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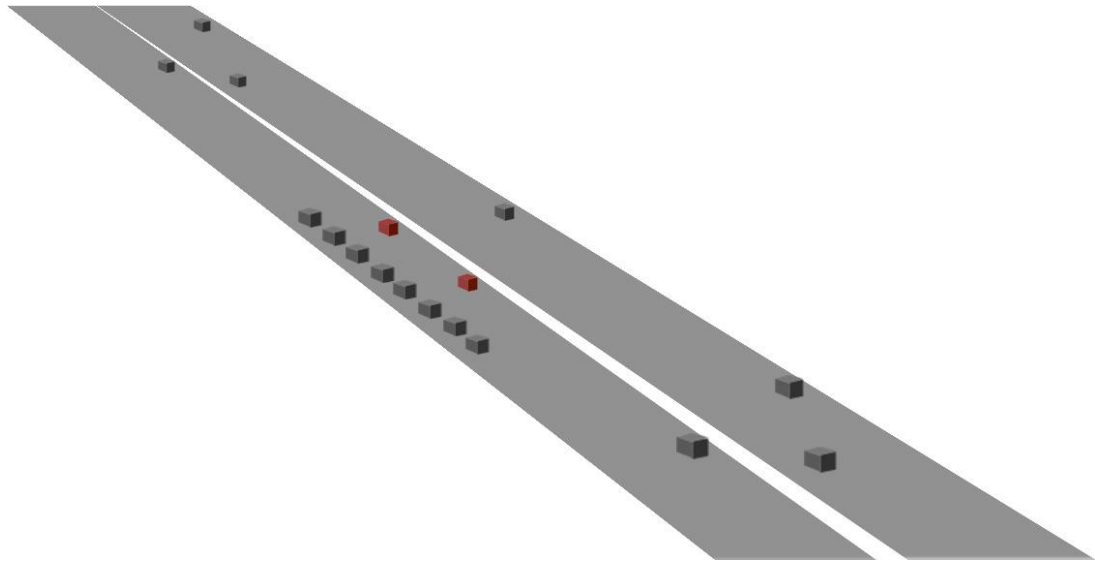
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Behavioural adaptation of drivers of unequipped vehicles to short time headways observed in a vehicle platoon



Thesis submitted for the degree of Doctor of Philosophy

Transport Research Laboratory

- Affiliated Research Centre of the Open University -

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June 2013

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ABSTRACT

Advanced driver assistance systems (ADAS) are increasingly present within modern vehicles, supporting the introduction of semi- and fully-automated driving situations. As a consequence, a mixed traffic situation is likely to emerge where vehicles equipped with different degrees of automated systems will interact with unequipped vehicle drivers (UVDs). Platoons of vehicles comprise a vision for future traffic and are designed to maintain small headways in order to have a beneficial effect on both energy consumption and traffic flow.

The overarching aim of this work was to investigate whether the presence of automated vehicle platoons will impact UVDs' car-following behaviour. This required understanding in which conditions behavioural adaptation of UVDs can possibly emerge. Therefore, four studies were conducted using a car simulator whereby participants drove behind a lead vehicle in the vicinity of automated platoons of vehicles exhibiting different headway characteristics. Further external factors were varied across the different simulator studies.

In summary, when drivers were motivated by instructions and not impeded by keeping track of a lead vehicle, expected changes in behaviour were noticed: reductions in mean THW, minimum THW, amount of time spent below a critical THW and the variation of lane position were observed when driving next to a platoon with short THWs. Contrarily, there was no significant effect of platoons' headway when UVDs followed a lead vehicle as a result of congested traffic.

It was interpreted that elements of the environment as well as driver's cognitive state such as workload and motivation influenced the magnitude of the effects. Other factors are still unclear such as the influence of drivers' personality and driving skills. More work is needed to understand fully the conditions that promote behavioural change. Beyond the scope presented here, further research is also needed to understand how increasing deployment of vehicles equipped with ADAS may affect driver behaviour across the wider vehicle fleet.

LIST OF CONTENT

ACKNOWLEDGEMENTS	1
ABSTRACT	2
LIST OF CONTENT	3
LIST OF FIGURES	7
LIST OF TABLES	11
LIST OF ABBREVIATIONS	13
1 INTRODUCTION	16
1.1 State of the research	16
1.2 Aims and objectives of the work	20
1.3 Thesis outline	21
1.4 Publication emerging from thesis	24
2 LITERATURE REVIEW	25
2.1 Introduction	25
2.2 Advanced Driver Assistance Systems and automated driving	25
2.2.1 The benefits of ADAS and automated driving	25
2.2.2 From ADAS to automated driving	26
2.2.3 ADAS intervening in the driving task	28
2.2.4 Automated driving categories	30
2.3 Behavioural adaptation	35
2.3.1 Definition	35
2.3.2 Motivational models	37
2.3.3 Trust models	39
2.3.4 Social psychological models	41
2.3.5 The influence of personality	43
2.3.6 Behavioural adaptation to platooning	44
2.3.7 Behavioural adaptation of the non-equipped drivers	48
2.4 Car-following task	49
2.4.1 Safety margins	50
2.4.2 Car-following models	55
2.5 Summary of the literature review	59
2.6 Conclusion of the literature review	61
3 METHODOLOGY	63
3.1 Driving simulator	63
3.2 Psychophysical method of limits	66

4	FIRST EXPERIMENTAL STUDY	69
4.1	Introduction.....	69
4.2	Hypothesis	69
4.3	Method.....	69
4.3.1	Participants	69
4.3.2	TRL's driving simulator.....	70
4.3.3	Driving environment	71
4.3.4	Experimental design and procedure	71
4.3.5	Measures.....	74
4.3.6	Analysis.....	74
4.4	Results.....	75
4.5	Limitations.....	76
4.6	Discussion.....	76
4.7	Conclusions.....	77
5	SECOND EXPERIMENTAL STUDY: A CONFORMITY STUDY	78
5.1	Introduction.....	78
5.2	Hypotheses and explorative questions	79
5.3	Method.....	80
5.3.1	Participants	80
5.3.2	Apparatus	81
5.3.3	Driving environment	81
5.3.4	Experimental design and procedure	84
5.3.5	Independent variables.....	85
5.3.6	Dependent variables	89
5.3.7	Analysis.....	91
5.4	Results.....	91
5.4.1	Results obtained with the psychophysical method of limits.....	91
5.4.2	Results of simulator drive.....	93
5.4.3	Personality and minimum adopted/preferred THW	96
5.5	Discussion.....	97
5.6	Conclusions.....	100
6	THIRD EXPERIMENTAL STUDY: THE EFFECT OF SHORT TIME HEADWAYS.....	103
6.1	Introduction.....	103
6.2	Hypotheses.....	104
6.3	Method.....	105

6.3.1	Participants	105
6.3.2	Material.....	106
6.3.3	Experimental design and procedure.....	106
6.3.4	Measures	109
6.3.5	Analysis	109
6.4	Results.....	110
6.4.1	Following tactic	110
6.4.2	Following safety	113
6.4.3	Lateral deviation	118
6.4.4	THW over time	118
6.5	Discussion	123
6.5.1	Effect on following behaviour	123
6.5.2	Effect on lateral deviation.....	125
6.5.3	Carryover effect.....	125
6.5.4	THW over time	127
6.6	Conclusions.....	129
7	FOURTH EXPERIMENTAL STUDY: IMPLICIT CAR-FOLLOWING SITUATION	132
7.1	Introduction.....	132
7.2	Hypotheses	133
7.3	Method	134
7.3.1	Participants	134
7.3.2	Material.....	134
7.3.3	Driving environment.....	135
7.3.4	Experimental design and procedure.....	135
7.3.5	Procedure	138
7.3.6	Behavioural measures.....	138
7.3.7	Subjective measures.....	139
7.3.8	Data preparation.....	139
7.3.9	Data analysis.....	145
7.4	Results.....	145
7.4.1	Mean THW during the lane closure.....	146
7.4.2	Minimum THW during the lane closure.....	147
7.4.3	Minimum THW before overtaking	148
7.4.4	Subjective data.....	148
7.4.5	Platoon perception	150
7.4.6	Workload	151
7.5	Discussion and conclusions.....	152
8	DISCUSSION.....	156

8.1	Summary of the experimental studies.....	156
8.2	Research contribution	158
8.2.1	Contribution according to the original PhD objectives	158
8.2.2	Implications of the research	161
8.3	Limitations.....	165
8.4	Further research and outlook	167
8.4.1	Mechanisms underlying behavioural adaptation	168
8.4.2	Further variables.....	169
8.4.3	Countermeasures	171
9	CONCLUSIONS.....	172
10	LITERATURE	174
	APPENDIX A: Participants' written consent form used in all studies.....	186
	APPENDIX B: Participants' instruction used in the 1st experimental study	187
	Participant information.....	187
	APPENDIX C: Participants' questionnaire used in the 1 st and 3 rd experimental studies	188
	APPENDIX D: Participants' debriefing sheet used in all studies	189
	APPENDIX E: Participants' instruction used in the 2 nd experimental study (without part 2 and 3 in the 3 rd experimental study)	190
	APPENDIX F: Participants' questionnaire used in the 2 nd and 4 th experimental studies	192
	APPENDIX G: Participants' instruction used in the 4 th experimental study.....	203
	APPENDIX H: Key criteria of the psychophysical method of limits	204
	Reliability	204
	Variability.....	205

LIST OF FIGURES

<i>Figure 1 Schematic presentation of the thesis outline</i>	<i>23</i>
<i>Figure 2 The driving task as a system composed by drivers, input and output variables in the context of the present work.</i>	<i>25</i>
<i>Figure 3 The five-layer PATH-AHS control system architecture © 2002 IEEE.....</i>	<i>32</i>
<i>Figure 4 Component of a truck platoon as developed in KONVOI (reproduced with permission of the Transportation Research Board)</i>	<i>34</i>
<i>Figure 5 “Risk Homeostasis Theory” (RHT) from Wilde (1982)</i>	<i>37</i>
<i>Figure 6 The task–capability interface model from Fuller (2005)</i>	<i>39</i>
<i>Figure 7 Simplified model according to the theory of planed behaviour (TPB) by Ajzen and Madden (1986).....</i>	<i>41</i>
<i>Figure 8 Graphical representation of the factors involved in SEEV model after Wickens and colleagues (2001).....</i>	<i>48</i>
<i>Figure 9 Threshold of the Action Point Models and process of following behaviour in action point model (with Δx for space headway and Δv for speed difference) (source: Olstam and Tapani, 2004; according to the model presented in Wiedeman and Reiter, 1992)</i>	<i>57</i>
<i>Figure 10 A typical 'close following spiral' (Brackstone et al., 2002).....</i>	<i>58</i>
<i>Figure 11 TRL fixed-base driving simulator.....</i>	<i>70</i>
<i>Figure 12 TRL driving simulator: control room.....</i>	<i>71</i>
<i>Figure 13 Screenshot of the simulator environment showing the participants’ vehicle (in a red circle) and lead vehicle in the middle lane and the platoon with time headway of 0.3 s (in condition THW03) and 1.0 s (in condition THW10) in the left lane.</i>	<i>72</i>
<i>Figure 14 Set-up of the low-level simulator.....</i>	<i>81</i>
<i>Figure 15 Example of a simulated road section used for the trial.....</i>	<i>82</i>
<i>Figure 16 road angle (a) and road perspective from the top (b).....</i>	<i>82</i>
<i>Figure 17 Four semi-circles limiting the swarm around the ‘ego’ car</i>	<i>83</i>
<i>Figure 18 Warning messages display over the simulated environment, reminding drivers to stay in the same lane and not too far from the LV (THW < 8 s)</i>	<i>86</i>

<i>Figure 19 Schema of the study design in conditions THW10 and THW03</i>	87
<i>Figure 20 The psychophysical method of limits implemented for the assessment of preferred THW includes the presentation of a set of (a) increasing THWs starting with a very small THW (0.1 sec) and (b) decreasing THWs starting with a large THW (2.5 sec).</i>	88
<i>Figure 21 Structure of dependent variables considered for the data analysis of the second experimental study</i>	89
<i>Figure 22 Data sample for one participant as an example for THW data when plotted over time</i> ..	90
<i>Figure 23 Averaged minimum preferred and minimum adopted THW and standard error (+/- 2SE) in the three traffic conditions (BL, THW03, THW10) (N = 42)</i>	92
<i>Figure 24 Averaged adopted mean THW and standard error (+/- 2SE) in the three traffic conditions (BL, THW03, THW10) (N = 42)</i>	93
<i>Figure 25 mean THW every minutes, 5 in total (N = 42)</i>	94
<i>Figure 26 Minimum TTC and standard error (+/- 2SE) in the three traffic conditions (BL, THW03, THW10) (N = 42)</i>	95
<i>Figure 27 The effect of traffic condition (BL, THW03, THW10) on subjective workload as measured by NASA-TLX on a 0-100 scale (error bars represent +/- 2SE) (N = 42)</i>	96
<i>Figure 28 Relationship between preferred THW and adopted THW</i>	100
<i>Figure 29 Presence of speed camera signs on roadside infrastructure</i>	101
<i>Figure 32 Screenshots from the simulated three-lane motorway with platoons in the inside lane, LV in the middle lane in THW14 and THW03 and no platoons in BL.</i>	107
<i>Figure 33 Schema of the study design</i>	109
<i>Figure 34 mean THW [s] in Baseline for each group (Group Small-Large started with THW03 first and Large-Small with THW14) and standard error (+/- 2SE) (N = 30)</i>	110
<i>Figure 35 mean THW [s] in platoon conditions (THW03 and THW14) for each group (Small-Large started with THW03 first and Large-Small with THW14) and standard error (+/- 2SE) (N = 30)</i>	111
<i>Figure 36 Mean THW [s] in condition THW03 and THW14 for groups Small-Large and Large-Small when driving next to a platoon or between two platoons (N = 30)</i>	113

<i>Figure 37 Averaged minimum (a) and maximum (b) THW [s] in platoon conditions (THW03 and THW14) for each group (Small-Large started with THW03 first and Large-Small with THW14) and standard error (+/- 2SE) (N = 30).....</i>	<i>115</i>
<i>Figure 38 Percentage of time headway [%] under the critical threshold of 1 s in the two platoon conditions (THW 03 and THW14) (N = 30)</i>	<i>116</i>
<i>Figure 39 Percentage of time spent under the critical threshold of 1 s for participants showing a value not equal to 0 in the two conditions THW3 and THW14 (N = 17).....</i>	<i>117</i>
<i>Figure 40 Averaged minimum TTC [s] in platoon conditions for each group (Small-Large started with THW03 first and Large-Small with THW14) and standard error (+/- 2SE) (N = 30).....</i>	<i>117</i>
<i>Figure 41 Mean SDLP in platoon conditions and baseline [m] +/- 2SE for each group (Small-Large started with THW03 first and Large-Small with THW14) (N = 30).....</i>	<i>118</i>
<i>Figure 42 Scatter plot with line of best fit for mean THW and SD of THW in condition BL (a), THW03 (b), THW14 (c) (N = 30).....</i>	<i>120</i>
<i>Figure 43 Difference between drivers in the frequencies, amplitudes and mean THW through the different conditions illustrated by means of three data-sets (N6, N3, N1).....</i>	<i>122</i>
<i>Figure 44 Schema of the study design in conditions THW14 and THW03</i>	<i>136</i>
<i>Figure 45 Road scenes from the simulated three-lane motorway during a lane closure, with platoons in the inside lane and LV in the middle lane.</i>	<i>137</i>
<i>Figure 46 Example of one participant's THW showing an approaching behaviour (in the red box).</i>	<i>140</i>
<i>Figure 47 Example of one participant's THW showing a preparation to overtake (in the red box)</i>	<i>141</i>
<i>Figure 48 Procedure to determine a pattern to cut the data, exemplified with data from participant nr. 9, block 2</i>	<i>142</i>
<i>Figure 49 Car-following 'spiral' from participant 9, Baseline, block 3</i>	<i>144</i>
<i>Figure 50 Bar chart to show a count of the responses to the question "Did you notice the difference between the three active drives?" across the two order groups (Small-Large and Large-Small) (N = 30)</i>	<i>151</i>

<i>Figure 51 Scores of the NASA-TLX in the two conditions THW03 and THW14 (N = 30)</i>	<i>152</i>
<i>Figure 30 Scatter plot with line of best fit for minimum adopted and preferred THW in condition BL (a), THW03 (b), THW10 (c) (N = 42)</i>	<i>206</i>
<i>Figure 31 Mean rating on a scale completed after each simulator drive for the measure of adopted THW (N = 42): participants had to rate the distance kept in the previous drive on a scale from 1 (=very close) to 7 (= very far).....</i>	<i>207</i>

LIST OF TABLES

<i>Table 1 10 points scale of different degrees of automation (Sheridan & Verplank, 1978).....</i>	<i>28</i>
<i>Table 2 Stimuli series (Skottke, 2007) (copied with authorisation of the copyright holders)</i>	<i>46</i>
<i>Table 3 Assets and drawbacks of driving simulators and field studies</i>	<i>66</i>
<i>Table 4 Experimental design of the first experimental study</i>	<i>73</i>
<i>Table 5 Descriptive statistics of mean THW, min THW and percentage of time spent under 1s (mean and standard deviation) for the two platoon conditions and the baseline</i>	<i>75</i>
<i>Table 6 Results of the independent t-test on mean THW, minimum THW and percentage of time spent under 1s</i>	<i>76</i>
<i>Table 7 Overview of the study design (the orders of simulator drives and drives for the psychophysical method of limits were counterbalanced)</i>	<i>85</i>
<i>Table 8 Spearman's rho correlation between personality characteristics/ attributes and minimum preferred/ adopted THW (* Correlation is significant at the 0.05 level) (N = 42)</i>	<i>97</i>
<i>Table 9 Study design of the third experimental study</i>	<i>108</i>
<i>Table 10 Study design of the third experimental study</i>	<i>138</i>
<i>Table 11 Overview of 1) the mean values cutting both the start and end of the data-set resulting from the two methods average and conservative and 2) outliers</i>	<i>143</i>
<i>Table 12 Results of the independent t-test on mean THW during the lane closure (block 2 and 3) in Baseline drive for Small-Large and Large-Small THW groups across data exclusion methods</i>	<i>145</i>
<i>Table 13 Results of the independent t-test on min THW during the lane closure (block 2 and 3) in Baseline drive for Small-Large and Large-Small THW groups across data exclusion methods</i>	<i>146</i>
<i>Table 14 Mean THW and standard deviations in treatment conditions for all the data-sets (N = 30)</i>	<i>146</i>
<i>Table 15 Results of the 2 × 2 mixed ANOVA for mean THW in the data-sets average, conservative and ABX-SDX (N = 30)</i>	<i>147</i>
<i>Table 16 Averaged minimum THW scores and standard deviations in the treatment conditions for all the data-sets (N = 30)</i>	<i>147</i>

<i>Table 17 Results of the 2×2 mixed ANOVA for minimum THW in the data-sets average, conservative and ABX-SDX ($N = 30$)</i>	<i>148</i>
<i>Table 18 Spearman's rho correlation between personality characteristics/ attributes and mean THW in different traffic conditions and data-sets (* $p < 0.05$, ** $p < 0.01$) ($N = 30$)</i>	<i>150</i>
<i>Table 19 Overview of the objectives targeted in Chapter 1</i>	<i>156</i>
<i>Table 20 Overview of the studies</i>	<i>157</i>

LIST OF ABBREVIATIONS

<i>ABS</i>	<i>Anti-lock braking system</i>
<i>ACC</i>	<i>Adaptive Cruise Control</i>
<i>ADAS</i>	<i>Advanced Driver Assistance System</i>
<i>AHS</i>	<i>Automated Highway System</i>
<i>BAS</i>	<i>Brake Assist System</i>
<i>BMBF</i>	<i>Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research in Germany)</i>
<i>CACC</i>	<i>Cooperative Adaptive Cruise Control</i>
<i>CHAUFFEUR</i>	<i>European Commission-funded truck-platooning research project</i>
<i>CMOS</i>	<i>Complementary metal–oxide–semiconductor</i>
<i>DARPA</i>	<i>Defense Advanced Research Projects Agency</i>
<i>EC</i>	<i>European Commission</i>
<i>EU</i>	<i>European Union</i>
<i>EFAS</i>	<i>Einsatzszenarien für Fahrerassistenzsysteme im Güterverkehr</i>
<i>ESP</i>	<i>Electronic Stability Control</i>
<i>EVD</i>	<i>equipped vehicle's driver</i>
<i>FCW</i>	<i>Forward Collision Warning</i>
<i>FDI</i>	<i>field-dependence/independence</i>
<i>FV</i>	<i>Following vehicle</i>
<i>GPRS</i>	<i>General Packet Radio Service</i>
<i>GPS</i>	<i>Global Positioning System</i>
<i>GSM</i>	<i>Global System for Mobile</i>
<i>HGV</i>	<i>Heavy goods vehicles</i>
<i>Hz</i>	<i>Herz</i>
<i>HMI</i>	<i>Human machine interface</i>
<i>ISA</i>	<i>Intelligent Speed Adaptation</i>
<i>ITS</i>	<i>Intelligent Transport System</i>

<i>JND</i>	<i>Just noticeable difference</i>
<i>Km</i>	<i>Kilometre</i>
<i>Km/h</i>	<i>Kilometre per hour</i>
<i>KONVOI</i>	<i>Einsatz und Evaluierung von Lkw-Konvois im Güterverkehr</i>
<i>LIDAR</i>	<i>Light Detection and Ranging</i>
<i>LDW</i>	<i>Lane Departure Warning</i>
<i>LKA</i>	<i>Lane Keeping Assistant</i>
<i>LOA</i>	<i>Level of Automation</i>
<i>LV</i>	<i>Lead vehicle</i>
<i>m</i>	<i>meters</i>
<i>M</i>	<i>Mean value</i>
<i>MFG</i>	<i>Maßnahmenerstellung für den Einsatz von Fahrerassistenzsystemen im Güterverkehr</i>
<i>NASA-TLX</i>	<i>National Aeronautics and Space Administration-Task Load Index</i>
<i>Mph</i>	<i>Miles per hour</i>
<i>NAHSC</i>	<i>National Automated Highway System Consortium</i>
<i>OECD</i>	<i>Organisation for Economic Co-operation and Development</i>
<i>OEM</i>	<i>Original equipment manufacturer</i>
<i>PATH</i>	<i>Partners for Advanced Transit Highways</i>
<i>PROMETHEUS</i>	<i>Program for a European Traffic with Highest Efficiency and Unprecedented Safety</i>
<i>RHT</i>	<i>Risk homeostasis theory</i>
<i>RAT</i>	<i>Risk allostasis theory</i>
<i>RWTH</i>	<i>Rheinisch–Westfälische Technische Hochschule (Rhine–Westfalian Technical University in Aachen, Germany)</i>
<i>SARTRE</i>	<i>Safe Road Trains for the Environment</i>
<i>s</i>	<i>second</i>
<i>SD</i>	<i>Standard deviation</i>

<i>SDLP</i>	<i>Standard deviation of lateral position</i>
<i>THW</i>	<i>Time headway</i>
<i>TTC</i>	<i>Time-to-collision</i>
<i>UN/ECE</i>	<i>United Nations Economic Committee for Europe</i>
<i>UVD</i>	<i>unequipped vehicle's driver</i>
<i>UMTS</i>	<i>Universal Mobile Telecommunications System</i>
<i>V2V</i>	<i>vehicle-to-vehicle</i>
<i>V2I</i>	<i>vehicle-to-infrastructure</i>
<i>WLAN</i>	<i>Wireless Local Area Network</i>
<i>yd</i>	<i>yard</i>

1 INTRODUCTION

1.1 State of the research

Significant technical progress over the last thirty years has increased the capability for a vehicle to collect information about the driving environment, to support the driver in the execution of manoeuvres and to communicate with other vehicles or infrastructure. Several milestones have demonstrated that the grouping of all these capabilities makes fully-automated driving a possibility. The idea of an automated vehicle was launched by General Motors at the 1939 World's Fair (Geddes, 1940) and the first operating automated car was developed around 1980 by the pioneering work of Ernst Dickmanns and his team at the Bundeswehr University and in cooperation with Mercedes-Benz (Dickmanns, 2002). In 1994, at the EUREKA-PROMETHEUS project's (1987 - 1995) final demonstration, Ernst Dickmanns and his team demonstrated that their driverless cars were able to drive more than thousand kilometres in real traffic conditions on the motorway (Dickmanns, 2002). Further progress in automated driving was inspired by various technology competitions. In 2005, the DARPA Grand Challenge attracted a variety of research and commercial organisations each of which had developed autonomous vehicles that were required to complete an off-road route (Buehler, Iagnemma, and Singh, 2007). In 2007, the DARPA Urban Challenge required autonomous vehicles to manage behaviour among other vehicles and obey traffic rules (Buehler, Iagnemma, and Singh, 2009). Subsequently, the 2010 VisLab Intercontinental Autonomous Challenge (Broggi et al., 2012) exposed supervised fully autonomous vehicles to general traffic, requiring the vehicles to drive 13,000 km from Parma, Italy to the World Expo in Shanghai, without human intervention. In 2012, Google announced that their fleet of Toyota Prius hybrids and Lexus RX hybrids had driven more than 500,000 km on public roads with only a few human interventions ("Look, no hands," 2012).

These milestones are showing that automated driving is technically achievable. Concretely, the introduction of automated driving occurs at two different speeds.

In the short-term, automation is developed and has been already implemented in public transit. CityMobil is a project sponsored by the European Commission (EC) (2006 – 2011) that aimed to

promote the public transit application of automated vehicles. One of the projects incorporated in CityMobil was the development of Personal Rapid Transit (PRT), which represents small automated vehicles that are sized to carry small groups and are operating on a dedicated network with markers (Berger et al., 2011). PRTs are already in operation in some airports such as Schiphol Airport in Amsterdam and London Heathrow. Semi-automated bus systems were implemented in the city of Eindhoven and represent another application of automated vehicles in public transit (Brookhuis and De Waard, 2006).

For the long-term view, automated driving will be available for domestic usage. Paving the way for full automation of vehicles, several Advanced Driver Assistance Systems (ADAS) are being developed and fitted in cars, taking over parts of the driving task. ADAS taking over either the lateral or longitudinal control of the vehicle are already on the market. ADAS combining the two are on the brink of the market such as the Autopilot system announced by Volkswagen (Bartels, Karrenberg, and Weiser, 2011). Two different lines of autonomous vehicles are emerging: individual 'self-driving' cars and cooperative automated systems. Information about the development of individual 'self-driving' cars is less accessible as development is being led by private companies including information technology companies such as Google as well as automotive manufacturers (e.g., Daimler-Benz, Volkswagen and BMW) and tier-one suppliers (e.g. Bosch and Continental). In contrast, the development of cooperative automated systems is generally undertaken by public institutions (e.g. U.S. Department of Transportation, European Commission) that are more inclined to publicise their work. Cooperative automated systems can, again, be divided into two different categories depending on whether they are operating directly on a standard motorway or on a separate, specialised route. The cooperative automated system developed in the United States called Automated Highway System (AHS) combines necessary on-board vehicle technologies with a range of intelligent technologies installed in the infrastructure of the dedicated lanes. Projects in this area has been traditionally lead by Partners for Advanced Transit and Highways (PATH) and National Automated Highway System Consortium (NAHSC) (Shladover, 2007).

Those systems designed to operate on normal, unmodified motorway will lead to a situation where equipped vehicles will mix with normal non-automated traffic. Platooning represents a form of

cooperative driving currently in development in Europe and assumed to be operating in mixed traffic on motorways (Lank, Haberstroh, and Wille, 2011). Within a platoon, the first vehicle is driven manually while the others follow automatically in single file at relatively short following distances.

Various forms of automation are developed and it is unclear which form of automation is most likely to emerge as the standard. The development of automated driving is influenced by, for example, road infrastructures, legal systems and by the nature of the organisations responsible for development (e.g. Government/internationally funded research, consortium, private companies). As defined by the EC sponsored small study SMART – 64, three institutional scenarios driving the introduction of automated driving are conceivable (SMART, 2011). In one scenario automated driving is promoted by governmental and supranational authorities. In another scenario, automated driving will percolate from individual vehicles becoming increasingly automated over time. This scenario is leading by industries responsible for the implementation of the automated systems in vehicles. The final scenario is based on ‘disruptive developments’. Disruptive developments do not evolve step by step but instead create a new market disrupting an existing one. In addition, it is possible to imagine a scenario involving coordination of government and industry activities (Shladover, 2012). Regardless which scenario will succeed in introducing automated driving, automated vehicles will all be based on the same common feature (section 2.2). By automating longitudinal control of vehicles and supported by vehicle-to-vehicle communication (V2V), gaps or time headway (THW) between automated vehicles will be reduced, increasing traffic capacity of the existing road infrastructure. Besides saving space and increasing the traffic flow (Van Arem, Van Driel, and Visser, 2006), tightly spaced vehicles have a positive effect on energy consumption induced by the slipstream effect (Zabat, Stabile, Farascaroli, and Browand, 1995). Therefore, it can be expected that automated driving will certainly be accompanied with a reduction of the distance between vehicles.

However, despite the encouraging technical results, autonomous vehicles raise a range of human factors issues. These include overreliance on automation, possible loss of situation awareness and loss of the skills needed to perform the automated functions manually (Parasuraman, Sheridan, and Wickens, 2000). These issues are especially critical in case of a system failure. Another issue relat-

ed to the introduction of on-board technologies resides in the fact that drivers can react in unexpected ways to the introduction of new systems, a phenomenon labelled “behavioural adaptation” (OECD., 1990). The literature is full of examples showing behavioural adaptation but these examples also show a high diversity in terms of the underlying factors and effect, which makes behavioural adaptation a complex phenomenon that is hard to predict, further work is therefore needed to better understand the complexity of behavioural adaptation (Saad, 2006). In addition, research on behavioural adaptation has tended to focus thus far on equipped vehicle drivers (EVDs) and neglected the unequipped vehicle drivers (UVDs). This approach is justified whilst the number of equipped vehicles remains negligible. However, in the perspective of mixed traffic and if automated systems change the behaviour of EVDs (i.e. reduction of distance between vehicles), a behavioural adaptation for UVDs is conceivable.

The EC co-funded SARTRE project on vehicle platooning identified a range of critical scenarios that could arise in mixed traffic and stressed that some of them are challenging (Robinson, Chan, and Coelingh, 2010). Simulator studies analysed subjective data from participants in the role of UVDs who interacted with a platoon to investigate the acceptance of the system (Lank et al., 2011) and to determine platooning requirements such as platoon length (Larburu, Sanchez, and Rodriguez, 2010). A field study investigating changes in behaviour of UVDs analysed their speed and overtaking time (Lank et al., 2011). Results of Lank et al. (2011) showed no difference in behaviour while overtaking between the platoon vehicles maintaining short distances of 10 m (11 yd) and the sample case with distances of 50 m between vehicles (54 yd). Nevertheless, work conducted so far has not considered the entire complexity of behavioural adaptation of the UVDs and more research is required in this field.

There is evidence for a behavioural adaptation of platoon drivers to short THWs kept during a platoon drive in the form of short THWs maintained after a platoon drive. Skottke (2007) conducted a range of studies at RWTH Aachen in the framework of the KONVOI project on truck-platooning and found that drivers, who were engaged in platoons holding short THWs, adapt their behaviour in keeping short THWs in the subsequent manual drive. The author interpreted the effect as a result of a change in the frame of reference: after a platoon drive with very short THWs, ‘normal’ THWs

appear very large leading drivers to reduce the THW they would normally keep. As visual processes are seen as responsible for behavioural adaptation, other drivers at risk would be UVDs who are not engaged in a platoon but driving in the vicinity of a platoon with short THWs clearly visible to them. Literature shows that a range of norms influence drivers behaviour (De Pelsmacker & Janssens, 2007) (section 2.3.4). Both the market penetration and functionality of ADAS is increasing; it is therefore conceivable that they may influence traffic norms. As visual processes seemed responsible for behavioural adaptation of platoon drivers to short THWs in platoons and because the increasing amount of vehicles keeping short THWs in traffic might change the norm related to THW, it is postulated here that UVDs observing smaller THWs within platoons may also experience a shift in their frame of reference. Consequently, they may reduce their own THW, increasing the probability of a rear-end accident.

1.2 Aims and objectives of the work

The major aim of this work is to investigate whether UVDs adapt their car following behaviour to the short THWs held in platoons. The objectives of this work can be summarised with the following points:

As the behavioural adaptation to THWs maintained by other vehicles in traffic has never been researched before, there is no existing methodology to build up on.

- Objective 1: It will thus be an objective to develop a methodology encapsulating the apparatus, the definition of relevant dependent variables and the creation of scenario enabling the analysis UVDs' behavioural adaptation to the short THWs maintained by automated vehicles.

Numerous parameters may influence the extent to which UVDs might adapt their behaviour to short THWs kept in platoons. These include exposure time and the frequency of exposure, the conspicuity of platoon vehicles, the length of platoon vehicles, the penetration rate and the aim of the drive. Also, drivers' individual characteristics might influence whether they adapt their behaviour.

- Objective 2: It will therefore be an objective of this work to find out which parameters of the environment are associated with the emergence of behavioural adaptation of UVDs to short THWs observed in platoons.
- Objective 3: Furthermore, the third objective is to investigate if there are inter-individual characteristics responsible for differences in the way drivers adapt to the short THWs in platoons.

It is also important to investigate whether the presence of platoons might change the norm on THW and thereby influence UVDs in the vicinity in their choice of THW.

- Objective 4: The present study therefore investigates whether drivers were willing to keep a THW smaller than their preferred one to conform to the norm established.

A method of limits has therefore been used to assess participants' minimum preferred THW. This was compared with the THW they adopted during simulated drives.

To investigate the impact of short THWs on the UVDs' car-following behaviour requires a good understanding of the overall processes of car-following. Car-following models (section 2.4.2) intend to describe the processes by which drivers follow each other. Microscopic simulation models attempt to understand the processes at the individual driver level. However, as already criticised in the literature, microscopic models do generally not incorporate human parameters that would enable to understand the inter- and intra- individual differences in car-following.

- Objective 5: The final objective will be thus to explore and try to identify key inter- and intra- individual differences in the car-following task.

1.3 Thesis outline

The research reported in this thesis provides the evaluation of any risk of a behavioural adaptation of the UVD to short THWs kept in a platoon using a range of experimental studies. This evaluation will provide a first contribution into a new research area, interested in the behavioural adaptation of UVDs. An overview of the thesis format is shown in Figure 1.

A literature review (Chapter 2) and four simulator trials have been conducted to achieve the objectives. Chapter 3 presents the methodology used in these experimental studies.

Each simulator study reproduced a driving situation on a three-lane motorway with traffic comprising platoons. In each study, participants drove next to these platoons, where the vehicles' THW was varied in different conditions. As the research could not build on existing knowledge, a first experimental study (Chapter 4) was conducted to test whether behavioural adaptation to small THWs maintained in platoons is observable by the driver nearby and lead to the second experimental study (Chapter 5). The third study (Chapter 6) used the knowledge gathered in the previous study to improve the conditions favourable for behavioural adaptation. It was suspected that the behavioural adaptation observed in the third study could have been influenced by the fact that participants were explicitly asked to follow a lead vehicle. The fourth study (Chapter 7) tested whether behavioural adaptation could occur under a non-explicit car-following task. Results of all the studies are summarised in Chapter 8 and the implications of the findings are discussed. A critical analysis of the methodology used and recommendation for future follow-up research are also provided.

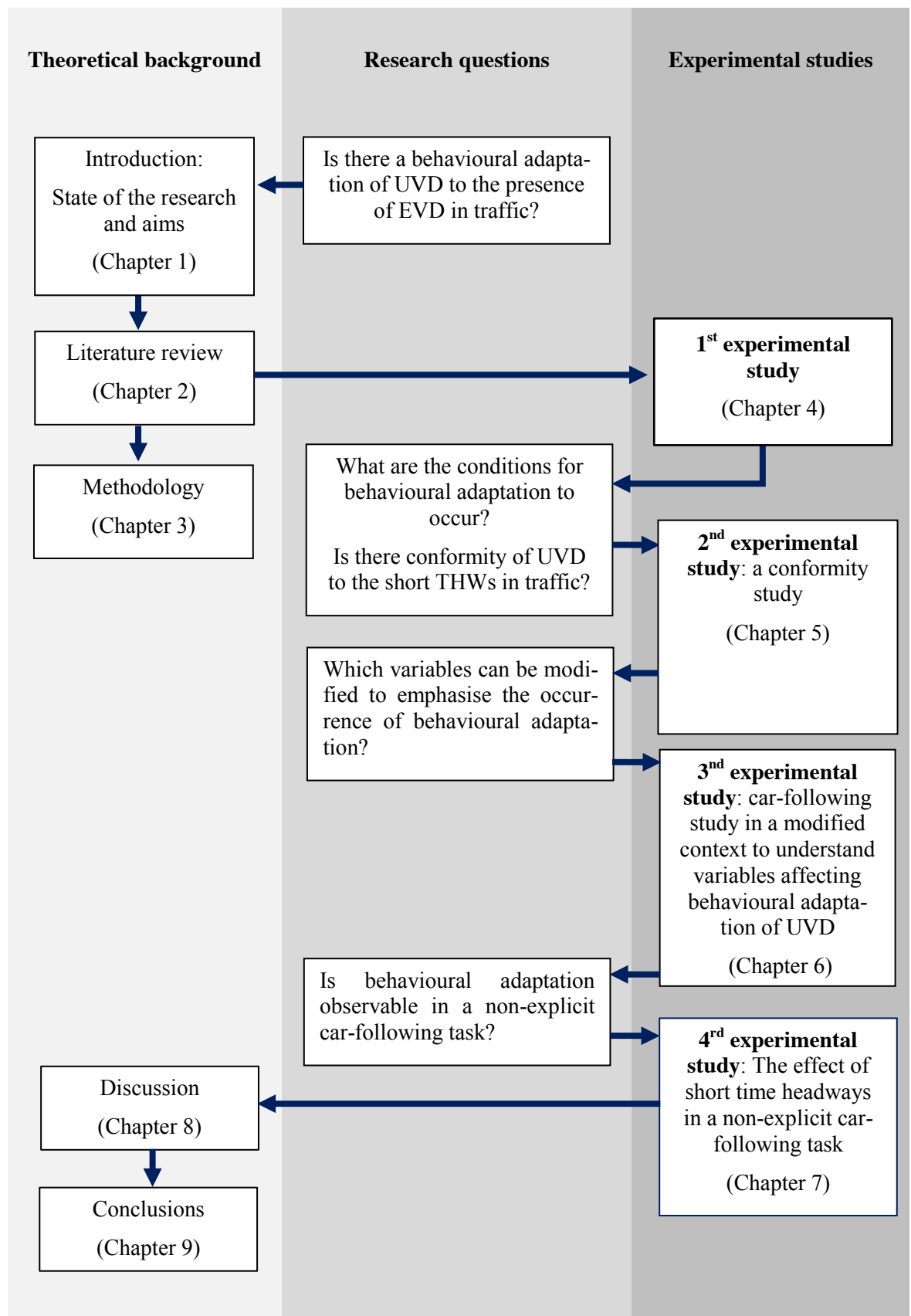


Figure 1 Schematic presentation of the thesis outline

1.4 Publication emerging from thesis

Peer-Reviewed Journals

- Gouy, M., Diels, C., Reed, N., Stevens, A. & Burnett, G. (2013). Do drivers reduce their headway to a lead vehicle due to the presence of platoons in traffic? A conformity study conducted within a simulator. *IET Intelligent Transport Systems journals*.

Conference Papers

- Gouy, M., Diels, C., Reed, N., Stevens, A. & Burnett, G. (2013). Preferred or adopted time headway? A driving simulator study. In M. Anderson (Ed), *Contemporary Ergonomics and Human Factors* (pp. 153–159). London: Taylor & Francis.
- Gouy, M., Diels, C., Reed, N., Stevens, A. & Burnett, G. (2012). The effects of short time headways within automated vehicle platoons on other drivers. In N. A. Stanton (Ed), *Advances in Human Aspects of Road and Rail Transportation* (pp. 529-538). Boca Raton, FL: CRC Press.
- Gouy, M., Diels, C., Reed, N., Stevens, A. & Burnett, G. (2012). Preferred time headway assessment with the method of limits. In P.V. Mora, J.-F. Pace and L. Mendoza (Eds), *Proceedings of European Conference on Human Centred Design for Intelligent Transport Systems* (pp. 87-93). HUMANIST Publications.

Presentations at Scientific Conferences

- Gouy, M., Diels, C., Reed, N., Stevens, A. & Burnett, G. (2012). Behavioural adaptation of the unequipped driver to small time headways held by automated vehicles in the traffic. *Presentation at the 5th International Conference on Traffic and Transport Psychology (ICTTP)*, Groningen.
- Gouy, M., Diels, C., Stevens, A. & Burnett, G. (2011). Die Anpassung des Fahrers eines nicht automatisierten Fahrzeugs an durch Automation verringerte Zeitabstände. *Präsentation an der 53. Tagung experimentell Arbeitender Psychologen (TeaP)*, Halle.
- Gouy, M. (2010). Wie fühlt es sich an, wenn die anderen Autos im Verkehr automatisiert sind, aber ich nicht? *Beitrag auf dem 4. Nachwuchsworkshop der Fachgruppe Verkehrspsychologie*, September 2010, Würzburg.

2 LITERATURE REVIEW

2.1 Introduction

The driving task can be seen as a system comprising drivers, input and output variables: stimuli (inputs) are perceived and processed by drivers resulting in a response (output). In this work, the stimulus is the small THW kept by automated vehicles in platoons; drivers' reactions to this stimulus are likely to be complex, and are considered here as having the potential to result in behavioural adaptation with the response being drivers' car-following behaviour (Figure 2). The three central elements of this system are defined in the literature review: Advanced Driver Assistance Systems (ADAS) and automated driving in section 2.2, drivers' behavioural adaptation to new systems in section 2.3 and car-following behaviour in section 2.4.

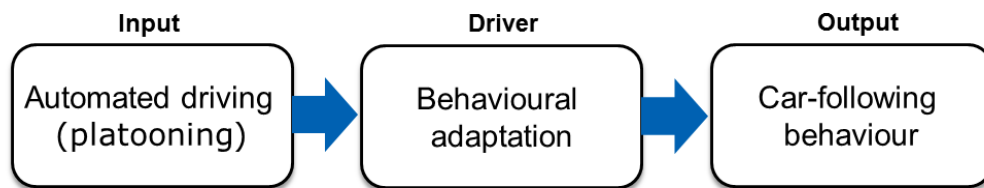


Figure 2 The driving task as a system composed by drivers, input and output variables in the context of the present work.

2.2 Advanced Driver Assistance Systems and automated driving

Automated driving arises as a combination of different Advanced Driver Assistance Systems (ADAS). Their usefulness is first introduced and their areas of deployment are described before addressing the technical aspects of ADAS that are relevant for automated driving. Subsequently, different emerging forms of automated driving are described. The perspective of this chapter is to give a brief overview about the research tradition in which automated driving is rooted and to convey all the efforts made for realisation of automated driving.

2.2.1 *The benefits of ADAS and automated driving*

The influence of human error in road accidents was revealed by a famous study from Treat and colleagues (1979). They investigated 2,258 road accidents and drew the conclusion that in 93% of

the accidents in their sample, human error was a contributory factor (against 34% of accidents where environmental factors were a contributor and 13% of accidents where vehicle factors contributed). Another famous study from Sabey and Taylor (1980) suggested that 95% of road accidents is partly due to human factors and 65% wholly.

Fuller has argued that road accidents occur when task demands exceed drivers' capabilities (Fuller, 2005). Hence, in a driving situation containing a large amount of relevant information generally, drivers' capability to attend to all the relevant information possibly reaches its limit. In such a situation of driving demand, drivers can fail to detect critical changes in the environment, leading to a collision. For instance, drivers may maintain that they did not see an object with which they have collided, even though this object was in an apparently clearly visible position within their field of view. This type of error has been classified as "looked-but-failed-to-see" (Brown, 2002) because it seems clear that the object passed within the driver's field of view but was not consciously detected. In other cases, drivers failed to detect critical changes because their eyes were taken off road.

Automated systems are designed to address this discrepancy; by sensing the driving environment and by providing the driver with information, warnings and/or direct assistance, it is envisaged that task demand is reduced thereby decreasing the likelihood that it will exceed drivers' capability and likewise the chance of an accident is diminished. Alongside with improvement in safety, automated systems are designed to improve energy efficiency of the driving task as one feature of automated vehicles is that they can keep tight time headways (THW) reducing the aerodynamic drag and thereby improving fuel efficiency (see for example Zabat et al., 1995). In addition, the combination of tight THWs and smooth, consistent traffic flow improves the road network capacity, tackling the issue of road congestion (Van Arem et al., 2006).

2.2.2 *From ADAS to automated driving*

Driving is a complex task that encompasses several sub-tasks. The scope of action for ADAS is therefore manifold. By and large, ADAS can be divided into categories; the most popular taxonomies to classify the large variety of different ADAS are based on: the level of intervention, the type of intervention and the level of automation.

- The level of intervention classifies ADAS depending on which of the three hierarchical levels of the driving task they support: the strategic, the tactical or the operational level (Michon, 1985). At the lowest level (operational level), control-based behaviours take place such as steering, braking, and speed control; ADAS corresponding to this level would be, for example, ESP (electronic stability program) or ABS (anti-lock braking system). On the intermediate level (tactical level) manoeuvre control is exercised by the drivers, which includes negotiating with traffic signs, other road users, merging and lane changing. An example for this category is the intersection assistance system that warns drivers if there are other road users on their trajectory if they want to accomplish a turning manoeuvre or change lane. Finally, decisions are made at the strategic level regarding means of transportation and the route to drive. An example within this level is the navigation system, which assists drivers in choosing an appropriate route.
- The type of intervention also provides a distinction between systems. By and large, three different categories can be distinguished (Carsten and Nilsson, 2001). Driver information systems provide information either related to the driving task (e.g. navigation, traffic or weather information) or unrelated to the driving task (e.g. e-mails). The second category represents driver warning systems that alert drivers of potential dangers, such as lane departure and, as a third category, intervening systems provide an active support to drivers in taking over parts of the driving task.
- Finally, one of the most cited taxonomy of levels of automation is that proposed by Sheridan and Verplank (1978). It divides automation into ten different levels, where the first level is full manual control and the tenth level represents full automation of a system (see Table 1). These automation levels also can be related to the four stages of human information processing (Information Acquisition, Information Analysis, Decision Selection, Action Implementation) (Parasuraman et al., 2000).

Each of the classifications presented in this section sheds light on one particular aspect of ADAS. Automated driving takes root in the development of ADAS and will thus encompass some different aspects of ADAS as contained in the different categories.

Table 1 10 points scale of different degrees of automation (Sheridan & Verplank, 1978)

The different levels of automation	
1	The computer offers no assistance; the human must do it all.
2	The computer offers a complete set of action alternatives, and
3	Narrows the selection down to a few, or
4	Suggests one, and
5	Execute that suggestion if the human approves, or
6	Allows the human a restricted time to veto before automatic execution, or
7	Execute automatically, then necessary inform the human, or
8	Informs him and her after execution only if he or she asks, or
9	Inform him or her after execution if it, the computer, decided to.
10	The computer decides everything and acts autonomously, ignoring the human.

2.2.3 ADAS intervening in the driving task

The following sections present systems actively intervening in the driving task in support of lateral and longitudinal control as these systems provide the building blocks for automated driving.

2.2.3.1 Lateral assistance

ADAS that preclude drivers from making unintended lane departures are based on systems able to recognise the road course and the relative position of the vehicle. Generally, components of these systems are a camera with a view of the road ahead (typically mounted behind the rear-view mirror), algorithms to detect road markings, a decision-making unit that decides about intervention requirement and actuators implementing the intervention in steering the vehicle back to the centre of the lane (Gayko, 2009).

2.2.3.2 Longitudinal assistance

Systems belonging to the longitudinal control of vehicles can be subdivided into different subcategories. A recent taxonomy of the ADAS functions supporting the longitudinal control of the vehicle was specified in a deliverable from the AIDE project (Floudas et al., 2005). Those actively intervening in the longitudinal control of the vehicle are the followings:

- Intelligent Speed Adaptation (ISA): refers to a system controlling the vehicle's speed so that drivers won't exceed the speed limit. ISA can be either informative or actively supporting drivers.
- Adaptive Cruise Control (ACC): is a radar-based system that senses slower vehicles ahead and adjusts speed to reach time headway (THW) set by drivers, and resumes the desired speed when the road ahead is clear. The system generally operates from a certain minimum speed. ACC can be completed by a curve management system that reduces the vehicle's speed when approaching a curve.
- Stop and go: provides automatic THW keeping such as ACC but operates down to 0 mph. These conditions include lower traffic speed, stop and go traffic, light controlled intersection and emergency braking situations.
- Collision avoidance systems: aim to avoid or mitigate a collision with an obstacle ahead. Two different approaches are being developed: the first provides only warning messages, the second offers an automatic braking intervention in case drivers fail to react. The same system can be applied to different scenarios. Other functionalities deriving from the collision avoidance system were dissociated in the AIDE taxonomy: intersection collision avoidance, rail-road crossing collision avoidance and pedestrian/obstacle detection.
- In addition, Cooperative Adaptive Cruise Control (CACC) is a further development of ACC that adds vehicle-vehicle communication providing ACC with more information from the lead vehicle (Van Arem et al., 2006). The ACC controller can therefore anticipate situation changes enabling a second vehicle to follow at a closer THW.

2.2.4 *Automated driving categories*

There is a global interest in the development of systems enabling automated driving because of the expected benefits. There are various types of automated driving, the developments of which are influenced by, for example, road infrastructures, legal systems and by the nature of the organisations responsible for development (e.g. Government/internationally funded research, consortium, private companies). By and large, two lines of development can be dissociated: individual ‘self-driving’ cars and cooperative automated systems. Little is known about the development of individual ‘self-driving’ as the interest is generally shared by private companies, which tend to keep their aims and results secret. The development of cooperative automated systems is generally taken over by public institutions that disseminate their purposes and results. These systems generally involve some form of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure communications (V2I). This section outlines the two different forms of cooperative automated systems in development: Automated highway systems and platooning.

2.2.4.1 *Automated highway systems (AHS)*

Automated highway systems (AHS) refer to systems in which a set of designated lanes enable the operation of appropriate equipped vehicles under complete automatic control, removing drivers completely from the control loop. AHS combined necessarily on-board systems and roadside infrastructure. Specifically, the idea of AHS as described by Horowitz and Varaiya (2002) is that users will drive the vehicle manually until the AHS entrance ramp and there indicate a destination turning control over to the automated system, which will handle the driving until the right exit is reached. When the right exit is reached, the ability to handle the car is checked and control is returned to driver.

Shladover (2007) detailed in a paper the main actors responsible for the development of AHS in the United States. The main actor for the development of AHS is the California Partners for Advanced Transit Highways (PATH), founded in 1986 and they received substantial research funding support from the California Department of Transportation (Caltrans) and the United States Federal Highway Administration (FHWA). In late 1994, the US Department of Transportation launched the

National Automated Highway System Consortium (NAHSC), a public-private partnership, which aims to investigate alternative AHS design. In August 1997, NAHSC successfully demonstrated key AHS technologies including an eight-vehicle platoon-based system in San Diego, CA. Despite of its success, the NAHSC was dissolved in 1998 and PATH continues to develop AHS technology. However, during the past decade the level of activity dedicated to the development of cooperative automated systems remained at a low level in the USA as proved by the lack of recent new publication in the research area.

The concept of AHS as developed in PATH entails multiple automated lanes separated from manual lanes. On each automated lane, vehicles form a platoon, which each of comprises one or more tightly spaced vehicles travelling together. Vehicles are also automated in the lateral direction. In the PATH-AHS structure, vehicles on automated lanes are given instruction by a system of five layers (Figure 3). The *network layer* estimates the highway network state based on information collected from roadside- and vehicle-based sensors. Based on this information, it determines the route of the trip. The *link layer* receives information on traffic state (speed, density, flow) and uses this to send back locally (for each 1 or 2 km stretch of highway) target values of speed, platoon size and lane changing manoeuvre to prepare an exit or to avoid an obstacle. The *coordination layer* coordinates the execution of manoeuvres among groups of vehicles. The *regulation layer* constitutes a conventional closed-loop control system with the *physical layer*. The *regulation layer* is responsible for executing manoeuvre commands from the *coordination layer* and report the completion of manoeuvres executed by the *physical layer* to the *coordination layer*.

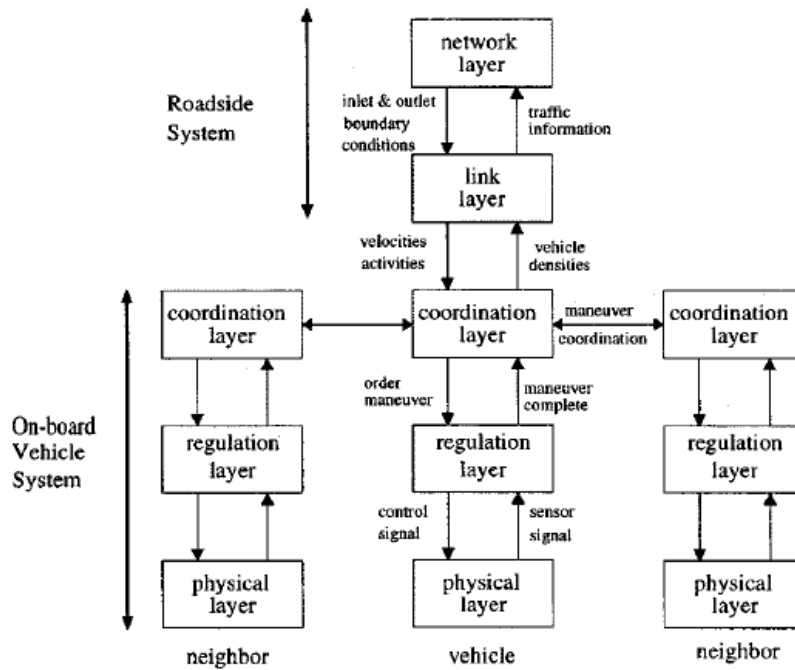


Figure 3 The five-layer PATH-AHS control system architecture © 2002 IEEE

2.2.4.2 Platooning

Following the tradition, the form of automated driving being developed in Europe entails the electronic coupling of vehicles by means of ADAS, named “platooning”. Within a platoon, the first vehicle is driven manually while the others follow automatically, and tightly spaced. The difference between AHS and the platoon is that AHS combines necessary on-board vehicle technologies with a range of intelligent technologies installed in the infrastructure of the dedicated lanes. In a platoon, on-board technologies are sufficient for the automation and no additional road infrastructure is required. Additionally, a platoon requires a manually driven lead vehicle.

This approach is different from the AHS concept, where it is asserted that automated vehicles must be separated from manual traffic and operating on dedicated lanes. In projects developing platooning this choice is justified by the increased reliability and reduced cost of electronic equipment and communication system (Robinson et al., 2010).

Many successive research projects have been aimed at developing and implementing the system. Firstly, the PROMETHEUS project (1988-1995) (Program for European Traffic with Highest Efficiency and Unprecedented Safety) achieved the technical development of an autonomous vehicle

(Dickmanns, 2002). The first step toward the development of platoons in Europe was made within the projects CHAUFFEUR I and II (2000-2003) that achieved a platoon of three vehicles electronically coupled (Harker, Sept 2001). Research on truck platooning was conducted in Germany with different projects financed by the Federal Ministry of Education and Research (BMBF): EFAS (2001-2002) (Preuschoff et al., 2003), MFG (2003-2004) (Savelsberg, 2005) and KONVOI (2005-2008) (Lank et al., 2011). Technical feasibility has been proven throughout the consecutive projects and research increasingly focuses on how to make the system useable and acceptable. The most recent project on general vehicle platooning SARTRE (Safe Road Trains for the Environment) (2009-2012), was co-funded by the European Commission and seven project partners and the aim of the project included (besides work on the technical development of platoons) defining a set of platooning strategies to operate on public motorways and determining business models to encourage the use of platoons (Dávila & Nombela, 2010, October).

Lank et al. (2011) explained how the KONVOI project imagined the function of a platoon (illustrated in Figure 4). Drivers that wish to cover a certain distance in a platoon communicate this intention to the system via a human-machine-interface (HMI). A connection to the central server is established by means of mobile communication (UMTS, GSM, GPRS). The KONVOI system transmits the vehicle's current GPS location, destination and desire to join a platoon to the central server. The central server scans for a platoon heading in a compatible direction and able to accept an additional vehicle. If a suitable platoon is found, the server informs the driver and subsequently monitors the merging process. Once drivers are sufficiently close to the platoon (60 m), a request is sent to the leading vehicle. If the request is accepted, the automated system takes over the lateral and longitudinal control of the vehicle. The distance between the vehicle that joins a platoon and the lead one is reduced to a target distance of 10 metres.

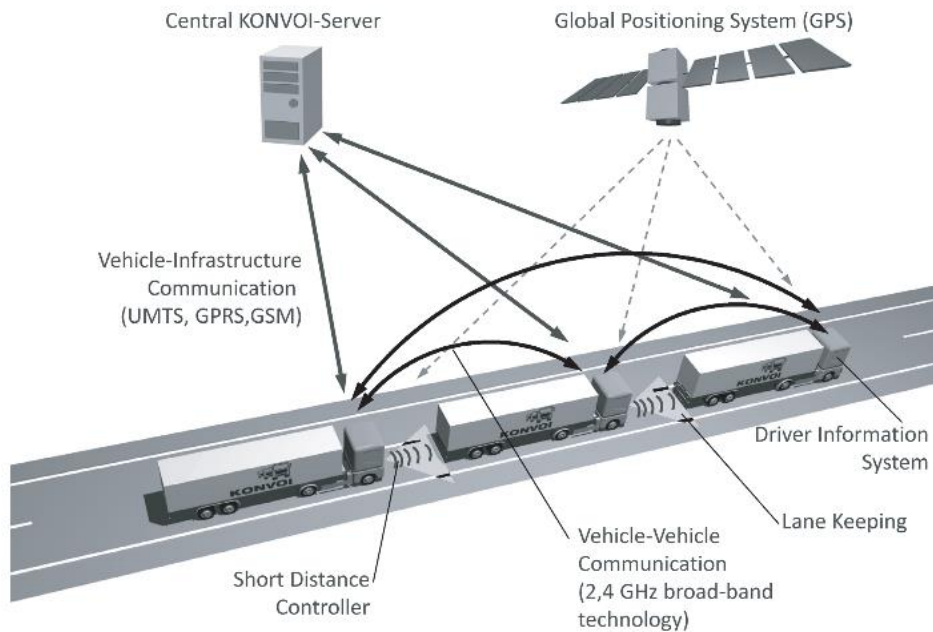


Figure 4 Component of a truck platoon as developed in KONVOI (reproduced with permission of the Transportation Research Board)

The system enabling platooning as developed in KONVOI combines several ADAS of which the main components are (Kunze, Ramakers, Henning, and Jeschke, 2009) :

- Actuators (steering and powertrain)
- Sensors: radar-sensor for object recognition in close-up, LIDAR-sensor for far-range, and CMOS-camera for lane recognition
- V2V communication over a wireless local area network (WLAN)
- Automation units (coordination of the different components)
- Control unit (Adaptive Cruise Control and automatic lane keeping guidance)
- Driver information system: human-machine-interface, central server (or organisation assistant), GPS and vehicle-infrastructure communication

Longitudinal control is taken over by an Adaptive Cruise Control (ACC) module based on distance sensor systems that capture the distance to the vehicle ahead and supported by V2V, ACC is able to keep a tight vehicle-vehicle distance safely. Lateral control is achieved by an automatic guidance system (or lane keeping system) based on image data processing (to identify current lane position)

and a distance sensor (to determine lateral offset of the driven vehicle in relation to the lead vehicle). A steering actuator delivers the necessary steering movement to correct the position of the vehicle in lane.

2.3 Behavioural adaptation

The previous section gives an overview about the technical aspects of automated driving and provides an optimistic view. Automated driving is clearly technically feasible, but the implications of automated driving on the human have not been extensively investigated so far although a research tradition has shown that drivers can react in a negative way to changes in the system. Also, the research has focussed thus far almost exclusively on the behavioural adaptation of the driver as a result of direct interaction with automated systems neglecting any effect on unequipped vehicle drivers (UVDs). With vehicles becoming increasingly automated, it is of paramount importance to consider behavioural adaptation of the UVDs in the development of automated systems and this work goes in this direction. After a general definition of behavioural adaptation, this chapter outlines different theories on behavioural adaptation before leading to the implications for platooning and UVDs in their vicinity.

2.3.1 Definition

The progressive introduction of ADAS and ultimately of automated vehicles will lead to mixed traffic scenario where UVDs will have to interact with equipped vehicles drivers (EVDs). In a mixed traffic scenario, changes in the behaviour of EVDs induced by automated system will almost certainly become visible by other drivers. Drivers will almost certainly adapt their behaviour to the perceived changes. In the process of adaptation to the new component of the system, drivers may adapt their behaviour in a way that reduces the expected safety or efficiency benefit of the system. An expert group of the OECD (1990) defined behavioural adaptation as:

“... those behaviours, which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change; behavioural adaptations occur as road users respond to changes in the road transport system such that their personal needs

are achieved as a result, they create a continuum of effects ranging from a positive increase in safety to a decrease in safety” (p. 23).

The research literature contains many examples of behavioural adaptation occurring with different types of ADAS such as ACC (Rudin-Brown and Parker, 2004) , Intelligent Speed Adaptation (ISA) (Comte, 2000), Lane-keeping assistance (LKA) (Breyer, Blaschke, Farber, Freyer, and Limbacher, 2010) , ABS (Sagberg, 1997), Night Vision Systems (Stanton and Pinot, 2000) , Navigation Systems (Forbes, 2009) and platooning (Eick & Debus, 2005; Skottke, 2007).

As noted by Saad (2006) a problem of research on behavioural adaptation is that literature is full of examples of different studies focusing on a certain ADAS type, whose results diverge in terms of magnitude and direction of the observed changes. As an example, in some studies the driving speed increased when using ACC (Hoedemaeker & Brookhuis, 1998), whereas in others this was not the case (Hogema, Janssen, and Coemet, 1996; Stanton, Young, and McCaulder, 1997; Törnros, Nilsson, Östlund, and Kircher, 2002). The difference in magnitude and direction make behavioural adaptation difficult to understand and to predict. Saad (2006) concluded that the underlying factors of behavioural adaptation are still not fully understood and more research with a careful methodology is needed to better understand them. Saad (2006) emphasised thereby the consideration of circumstantial conditions affecting behavioural changes being: the nature and extent of behavioural changes associated with the use of various support systems, the conditions in which these changes take place, the ‘reasons’ why these changes occur and the characteristics of the drivers more likely to present these behavioural changes. Furthermore, Saad (2006) advocated consideration of the temporal factors affecting behavioural adaptation. The introduction of an ADAS may impact drivers’ behaviour but the changes observed may develop as drivers first discover the system, learn all possibilities and limitations, becoming thus expert users.

Behavioural adaptation is thus a complex phenomenon because it has different origins. Rudin-Brown and Jamson (2013) provide an overview of theories in behavioural adaptation. The most well-known theories to explain the origin of behavioural adaptation are motivational models (risk and workload models). Trust theories developed in the area of automation are also suitable to explain behavioural adaptation. Less considered but perhaps also a contributing factor of behavioural

adaptation are social psychological processes. The influence of personality factors will be presented in this section too. Finally, recent works on behavioural adaptation to platoons have emphasised that visual processes can cause behavioural adaptation. The following sections will outline these various models.

2.3.2 Motivational models

Motivational models (risk and workload models) have been largely considered to explain a change in behaviour resulting from the introduction of a new system. Motivational models explain how drivers change their behaviour when facing risks or task difficulty (workload). The most famous risk model applied to the driving task is the “Risk Homeostasis Theory” (RHT) from Wilde (1982a). The model (Figure 5) argues that drivers have a target level of risk that they are willing to accept (a), which is compared to the perceived level of risk (b) via a comparator (c). If level of intrinsic risk in the environment is changed causing a discrepancy, drivers adapt their behaviour in order to recover their target level of risk (d). There is a feedback loop (e-f) influencing the perceived level of risk. One conclusion of this model is thus that regardless of which changes have been made in the traffic system or vehicle to improve safety, drivers would adapt their behaviour to recover the intrinsic target level of risk.

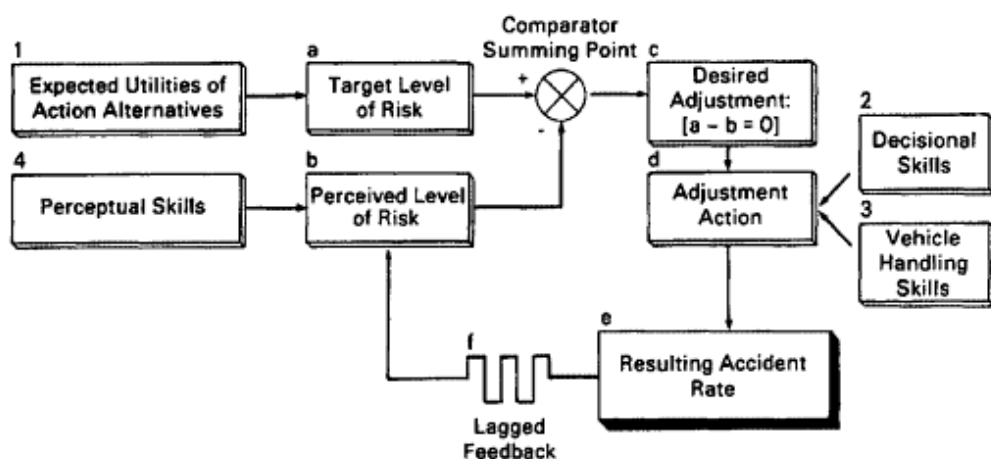


Figure 5 “Risk Homeostasis Theory” (RHT) from Wilde (1982)

An alternative to Wilde’s theory is the “zero-risk theory” from Nääätänen and Summala (1974) stating that drivers only consider risk a given threshold is exceeded (whereas in Wilde’s theory drivers

are posited as permanently assessing risk). Näätänen and Summala (1974) postulated a “subjective risk” alarming drivers when safety-thresholds are violated and prompting a change in behaviour, whereas according to Wilde’s theory driving behaviour should constantly adapt to changing risk levels. Fuller (2005) developed a theory based on the comparison between task demand and human capability: the task-capability interface model (Figure 6). When task demand exceeds capability the outcome is performance deterioration and loss of control and, inversely, when capability exceeds demands the outcome is that the task is experienced as very easy. A range of determining factors influence capability such as driver competence (information processing capacity and speed, reaction time, physical reach, motor coordination and perhaps flexibility and strength) that are in turn constrained by training and experience. However, this competence is not necessarily what is delivered at any moment of time because capability is vulnerable to a host of human factor variables such as attitude, motivation, effort, fatigue, drowsiness, time-of-day, drugs, distraction, emotion and stress. Task demand is determined by environmental factors, other road users, operational features of the vehicle being driven, speed and trajectory of the vehicle. However, drivers can modulate the task demand to reach and sustain a preferred arousal level. Speed choice for instance is one of the adjustments of task demand that drivers can make.

Risk Allostasis Theory (RAT) has developed from the task-capability interface model (Fuller, 2011). RAT includes the role of feelings in drivers’ behaviour and decision-making. In an experimental study, Fuller (2005) found that drivers’ self-reported feelings of risk correlated highly with their perceived demand of the driving task, when viewing video clips of driving at different speeds.

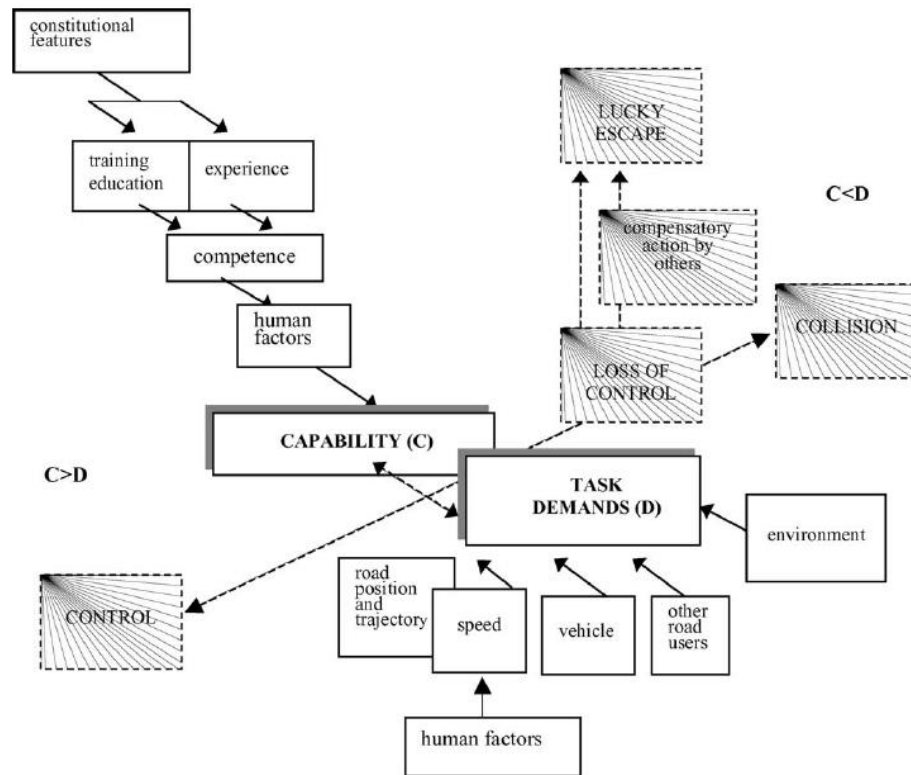


Figure 6 The task-capability interface model from Fuller (2005)

A major problem of the motivational theories is the lack of precision and as expressed by Rothengatter (2002), Wilde's and Fuller's theories fall into the 'homunculus trap' because they fail to specify how drivers compare external output with their own requirements. However, Damasio (2004) posite a mechanism by which the homunculus trap can be avoided with his concept of the "somatic marker hypothesis" suggesting that certain body states, emotions result from mostly learnt environmental triggers (Kinnear & Helman, 2013).

Furthermore, to consider only these models would reduce the origin of behavioural adaptation to either risk perception or workload. Other authors have suggested different origins for behavioural adaptation.

2.3.3 Trust models

Research in the realm of automation clearly shows that trust is required for the human to use an automated system. A very detailed literature review on trust in automation has been made by Lee (1976). In brief, the starting point is a comprehensive model of trust in automation established by

Muir (1994) explaining how an operator comes to trust a system. If an operator starts to trust a system too much, he becomes complacent and may fail to detect breakdown in the system (Parasuraman & Riley, 1997). In the qualitative model of behavioural adaptation from Rudin-Brown and Noy (2002), trust and personality traits jointly influence the formation of mental models that are in turn determining how drivers adapt their behaviour to new in-car systems. Two psychological variables are central in the theory from Rudin-Brown and Noy (2002): locus of control and sensation-seeking. The construct of locus of control (Rotter, 1966) is related to where individuals place the responsibility for outcomes of events and has two extremities: an individual with a high *internal* locus of control believes that their own actions are critical in shaping events whereas an individual with a high *external* locus of control believes external forces play the critical role in determining outcomes. Sensation-seeking is a personality trait defined by: *'the need for varied, novel, and complex sensations and experiences and the willingness to take physical and social risks for the sake of such experience'* (Zuckerman, 1979, p 27). The qualitative model proposes that behavioural adaptation to an in-car system will be more likely to occur in individuals who are classified as externals as they are more likely to trust automation. Also, the model predicts that high sensation-seekers will be more likely than low sensation-seekers to demonstrate behavioural adaptation to an in-car system because of their acceptance of higher levels of risk.

A study by Rudin-Brown and Parker (2004) illustrates the qualitative model of behavioural adaptation: the primary task included two drives with ACC with two different headway conditions and an unsupported drive. In addition, participants were instructed to perform a secondary task consisting in a number search task on an in-vehicle screen. Results show that compared to driving unsupported, participants located significantly more items per minute on a secondary task when using ACC while the variability of the lane position increased and the response to hazard was slower. The results suggest that drivers trusted the ACC to maintain headway and speed, allowing them to allocate more resource to a secondary task, not directly related to driving, while driving. According to the model predicting that externals would rely more on ACC, results show that externals were slower than internals in the response to hazards. In addition, the degradation of lane position was more pronounced by drivers scoring high in the sensation-seeking scale.

2.3.4 Social psychological models

Since the driver is not alone on the road, social psychological processes can be expected to influence the driver. Social psychology is the study of how thoughts, feelings and behaviours are influenced by the actual, imagined or implied presence of others (see for example Smith & Mackie, 2000). A great deal of research on the social psychology of driving has investigated the link between intentions and behaviour using the framework of the theory of reasoned action (TRA) (Ajzen & Fishbein, 1975, 1980; Fishbein & Ajzen, 1980) and its extension, the theory of planned behaviour (TPB) (Ajzen & Madden, 1986) (see for example Parker, Stradling, and Manstead, 1996). In brief, the TRA states that a person's behaviour is determined by his or her intention to perform this behaviour. Three theoretical constructs jointly determine behavioural intentions: attitude to behaviour, subjective norms, and perceived behavioural control. The attitudes toward the behaviour are formed by the product of an individual's behavioural beliefs about consequences and the evaluation of the outcomes (i.e. the seriousness of consequences). The subjective norm represents the perceived social pressure by significant others and reference groups and the motivation to comply.

The theory of planned behaviour (Figure 7) adds the construct of perceived behavioural control that refers to the individual's perceived ease or difficulty to perform the behaviour of interest.

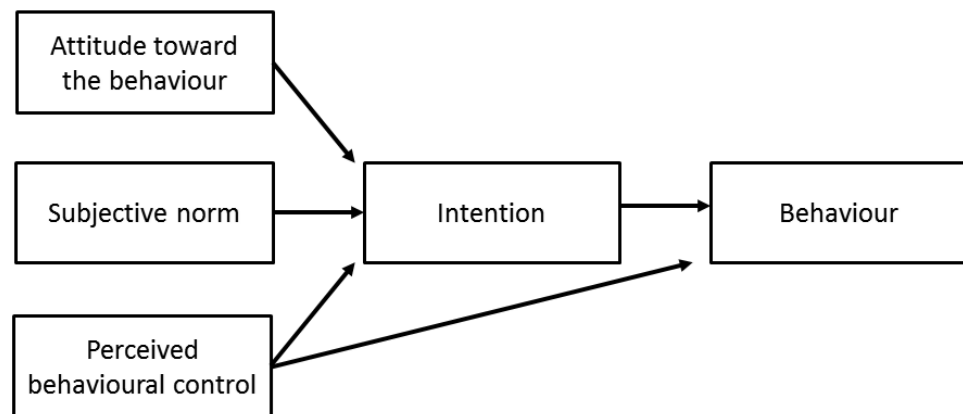


Figure 7 Simplified model according to the theory of planned behaviour (TPB) by Ajzen and Madden (1986)

In an extended TPB model, additional norms have been specified (normative, descriptive and personal) (De Pelsmacker & Janssens, 2007). The authors of the extended model specify that the 'significant others' affecting the subjective norms in the TPB (Ajzen & Madden, 1986) are rarely pre-

sent in driving situations and so have negligible influence. However, drivers can be influenced by the behaviour of other road users in general, which the authors refer to as the normative norm. In a number of studies, it was demonstrated that displaying to drivers the number of other road users that have not broken the speed limit previously on a particular road leads to a decrease of speed violation on that road (Van Houten & Nau, 1981). A similar study observed driver behaviour in response to Variable Message Signs (VMS) which carried information about the percentage of drivers who were not speeding and tailgating in the last few days (Groeger & Chapman, 1997). Results showed that the incidence of these behaviours reduced when the VMS messages were displayed. Descriptive norms are characterized by the imitation of other road users in the immediate vicinity. To illustrate this, several models exist which explain the process of the social contagion of speed (Connolly & Åberg, 1993). Limited but convincing empirical support of the models was provided by observational study of drivers' speed choice in following and free driving situations, showing that vehicles close to each other travel at similar speeds. More empirical evidence shows a significant correlation between observed speed and the speed of others as well as between a driver's estimate of own speed and their estimate of other's speed (Fildes, Rumbold, and Leening, 1991). Finally, personal norms determine what people should do in order to be consistent with their self-image. Before engaging in certain behaviour, people will consider the impact on their self-image. If the behaviour is inconsistent with the personal norm, the anticipated damages to the self-image inhibit the behaviour.

In summary, the extended TPB model (De Pelsmacker & Janssens, 2007) stresses the importance of the influence of others on behaviour. The presence is either imagined: in the normative norm the behaviour of others serve as a model ("That's what people do.") and in the personal norm the judgement of others is instrumental ("What will people think about it?"); or the presence of others is direct, real and visible, as reflected by the descriptive norm: drivers are inclined to imitate the observed behaviour of others surrounding them.

2.3.5 *The influence of personality*

Personality traits are thought to influence the individual's perception and appraisal of the environment (McCrae & Costa, 1995) and such appraisal is subsequently thought to affect behaviour. Rudin-Brown and Noy (2002), supported by literature evidence, incorporated in a qualitative model of behavioural adaptation the influence of personality, especially of Locus of Control (LoC) and Sensation-seeking (SS). After a literature review, Ulleberg and Rundmo (2003) selected five personality traits that have been demonstrated to have a significant relationship with risk-taking behaviour in traffic or involvement in accident, which could possibly related to behavioural adaptation: Sensation Seeking (SS), Anger (the tendency to experience anger and frustration), Anxiety (a tendency to be fearful, prone to worry and being nervous), Altruism (characterised by active concern for others) and Normlessness (i.e. the belief that socially unapproved behaviours are required to achieve certain goals). Altruistic and anxious participants tended to perceive the risk related to traffic accidents as high, as well as having a positive attitude toward traffic safety, reported at the same time less risk-taking in traffic (Ulleberg & Rundmo, 2003). Contrarily, high scores on SS, normlessness and Anger were associated with both risk-taking attitudes and risky driving behaviour. Explanation from Ulleberg and Rundmo (2003) was that sensation-seekers are expected to seek excitement and stimulation in traffic, individuals scoring high on the normlessness scale are not influenced by others when it comes to socially disapproved behaviours and finally, those scoring high on Anger are thought to be easily angered and frustrated which is manifested in aggressive behaviour in traffic such as tailgating. Similarly, drivers scoring high on these personality traits might certainly be encouraged and not afraid of adaptation their behaviour in a risky way following the introduction of ADAS and automated systems. A similar phenomenon might be observable by drivers scoring high on the Manchester Driver Behaviour Questionnaire (DBQ) (Lawton, Parker, Manstead, and Stradling, 1997). The DBQ is based on classification of self-reported driving failures into three categories: Highway Code Violations, Aggressive Violations, Lapses and Errors. There is evidence supporting the fact that DBQ can predict accident liability (see for example De Winter and Dodou, 2010).

Besides personality, cognitive styles might also impact drivers' behavioural adaptation. Cognitive style is a psychological construct separating individuals depending on how they think, perceive and remember information. Cognitive styles are not related to ability. Both styles and ability will affect performance on a given task but the basic distinction between them is that performance on all tasks will improve as ability increases, whereas the effect of style on performance will be either positive or negative depending on the nature of the task (Rayner & Riding, 1997). Additionally, there is evidence for the independence between cognitive styles and personality (Rayner & Riding, 1997). The concept of field-dependence/independence (FDI) (Witkin, Dyk, Faterson, Goodenough, and Karp, 1962) is a cognitive style that differentiates individuals between those who are field dependent in which case their perception is dominated by the immediately perceivable organisation of the environment. Those who are field independent have the capacity to overcome the given organisation in order to analyse its components. The impact of this cognitive style on drivers has been scarcely investigated but conclusions of work done so far is that field dependent drivers do not quickly recognize developing hazards, they are slower in responding to embedded road signs, have difficulties in learning to control a skidding vehicle and fail to drive defensively in high speed-traffic (for review see Goodenough, 1976). As field-dependent persons are highly influenced in their judgement by the organisation of their visual field, it can be predicted that field-dependent drivers might orientate their THW to the THWs held in traffic and might thus show a higher proneness to distance adaptation.

2.3.6 *Behavioural adaptation to platooning*

In the framework of the KONVOI project on truck platooning, Skottke (2007) investigated whether the small time headways (THW) adopted when driving within a platoon cause carry-over effects in the form of reduced THWs in the subsequent driving period after having left a platoon. The results of a first experimental trial in a car simulator showed that participants indeed adapt their behaviour to the small THW maintained in a platoon by choosing shorter THW after the platoon drive. Skottke (2007) subsequently investigated possible underlying factors causing this behavioural adapta-

tion: two subsequent experimental trials tested whether this behavioural adaptation is perception or action based.

The perception based component of behavioural adaptation

The idea is that behavioural adaptation occurs through a change in the frame of reference and the theories behind this take sources in the psychophysics and notably in theories about frame of references (Helson, 1947; 1964; cited in Skottke, 2007). Theories about frame of references consider the context as a key factor to judge a stimulus. For instance, a person is tall in a country where the majority of inhabitants are small but is considered small in a country where the majority of the inhabitants are tall.

To test the influence of a change in the frame of reference, two groups of participants were driving within a platoon and exposed to different sets of THWs with one group being exposed to sets of four “small distances” (from 0.3 s to 1.2 s) and the other group being exposed to sets of four “large distances” (from 0.9 s to 1.8 s) (see Table 2). Each group had to give their opinion about each of the different distance afterwards (close/far and comfortable/uncomfortable). Two of the four distances were similar between the two groups (0.9 s and 1.2 s) forming thus an overlapping condition that enabled a comparison between the two groups. The expectation was that the judgement of the overlapping stimuli would be evaluated as less aversive by the group confronted to “small distances” than by the group confronted to “large distances”. Of interest was also the time headway behaviour after the confrontation with the different distances in the platoon. The expectation here was that manual driving behaviour after leaving the platoon will be commensurate with the judgement of distance in the platoon. It was expected that participants judging the overlapping stimuli in a more aversive way would keep a larger distance and that the participants having a less aversive judgement would keep a smaller distance.

Table 2 Stimuli series (Skottke, 2007) (copied with authorisation of the copyright holders)

Group 1 (low series) (s)	0.3	0.6	0.9	1.2		
Group 2 (high series) (s)			0.9	1.2	1.5	1.8
			Overlapping stimuli, rated by subjects			

Results show that the group with large distances rated similar conditions as more aversive than the small distances group but the difference was statistically not significant. A second expectation was that driving behaviour changed as a consequence of the drivers’ judgements. The large distances group showed no pre-post effects; the small distances group reduced their THW after having been coupled with distances from 0.3 s to 1.2 s. Skottke (2007) concluded that the shift in the frame of reference changed drivers’ behaviour but not their judgement, suggesting that behavioural adaptation can occur unconsciously. However, it can also be interpreted that the measure of judgement is not as sensitive as the behavioural measure.

These results are in line with other evidence in the literature showing behavioural adaptation as the effect of a shift in drivers’ frame of reference, notably in studies on speed adaptation. Studies on speed adaptation have shown that after travelling at high speed, drivers will underestimate the velocity at which they are travelling (Casey & Lund, 1992; Denton, 1976; Matthews, 1978). In a simulator study, participants were required to decelerate a vehicle from 110 kph to 64 kph and subsequently underestimated their speed (Denton, 1976). In a field study, vehicles’ speed on a highway was assessed by means of radar deployed in a 80 km/h speed limit area (Matthews, 1978). The data from the northbound traffic that previously experienced a speed limit of 105 km/h were compared to the southbound traffic previously exposed to a speed limit of 64 km/h. Results show that northbound traffic velocities exceeded those of southbound traffic by an average of 6.9 km/h. In another field study, the speed of two groups were compared after each of the group had to drive at one specific speed, either low or high. The average speed of the group driving at higher speed was higher than the speeds of the group driving at lower speed (Casey & Lund, 1992).

The action based component of behavioural adaptation

The second approach is based on task switching theories (see for example Allport, Styles, and Hsieh, 1994). In a task switching paradigm, performance on repeated tasks is compared with performance when there is a requirement to switch between different tasks. Typically, reaction time and error rate are greater on task switch than on repetition trials (see e.g. Monsell, 2003, for review). This suggests that there is a shift cost appearing during shifting from one task set to another. Furthermore, Mayr and Keele (2000; cited in Skottke, 2007) demonstrated that the implementation of a new task requires the inhibition of the previous one (backward inhibition). As an expression of backward inhibition Mayr and Keele (2000) predicted increased response time when shifting to a task set that had to be abandoned recently and thus, suffers residual inhibition. Skottke (2007) transfers this effect from the micro level of reaction time in milliseconds to the macro level of traffic behaviour: drivers in a platoon experience small THWs and need to change the distance held to a lead vehicle when leaving the platoon to go back to a manual drive. However, this active change to appropriate THW is backward inhibited by the THW held during the drive in a platoon. Thus, drivers do not adopt new appropriate THW when driving manually after leaving a platoon but adopts similar THW to that within the platoon drive.

To test the hypothesis of backward inhibition, Skottke (2007) tested how behavioural adaptation changed after leaving a platoon. One of the scenarios tested whether drivers would jump to appropriate THWs, whereas the aim of the second scenario was to test if THW would linearly increase to an appropriate one. A jump could be interpreted as a task switch, delayed by the backward inhibition responsible for the behavioural adaptation. The results show neither evidence for a jump in the choice of the THW during the manual drive following the platoon drive nor for a linear change, drivers constantly kept the same THW as during the platoon drive. The study showed no evidence for backward inhibition but it however demonstrated behavioural adaptation resulting after a drive with small THW had a long lasting effect (lasting for at least 24 km).

In summary, Skottke's (2007) results support for the idea of shift in the frame of reference causing behavioural adaptation.

2.3.7 Behavioural adaptation of the non-equipped drivers

One of the difficulties in investigating the behavioural adaptation to EVDs is that the UVDs have to perceive changes induced by the EVDs in the first place. It is thus important to understand factors involved in the perception of changes by the UVDs. Wickens, Helleberg, Goh, Xu, and Horrey (2001) developed a descriptive model, the SEEV model (Salience, Expectancy, Effort and Value) to predict scanning and distribution of visual attention (Figure 8). The model is based on the assumption that the allocation of visual attention to different parts of the operators' field of view is guided by the influence of four factors: the *salience* of the signal, the *effort* needed to move attention from previously fixated location, the *expectancy* of the signal, the objective *value* of processing information. Expectancy and value can be labelled as top-down or as knowledge driven forces. In contrast, salience and information access effort may be considered bottom-up or environmentally driven forces. Salience, expectancy and value are positive forces that are attractive attention whereas effort is an inhibitory force.

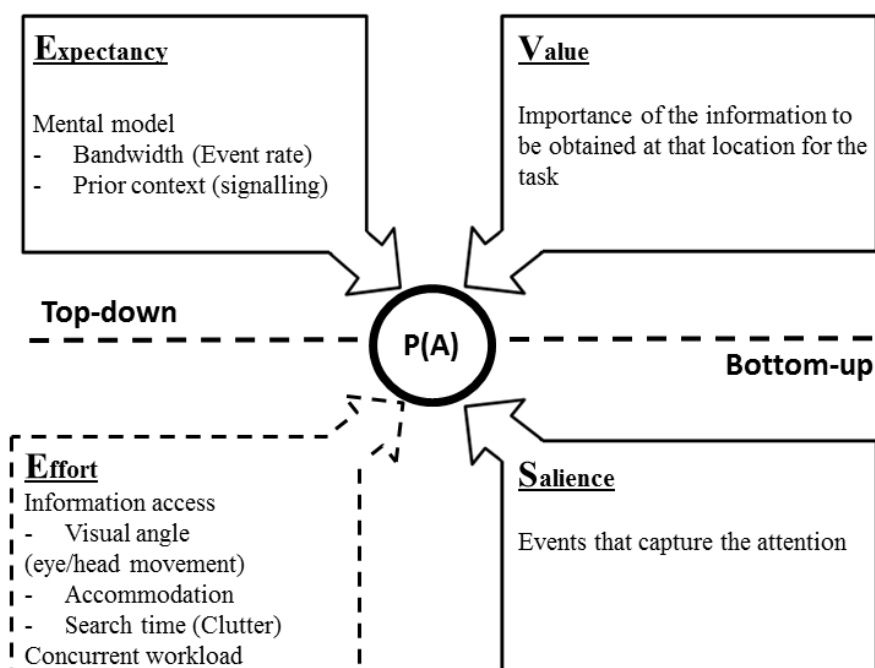


Figure 8 Graphical representation of the factors involved in SEEV model after Wickens and colleagues (2001)

Based upon the SEEV model, it appears clearly why investigating the behavioural adaptation of UVDs is difficult as compared with the behavioural adaptation of EVDs. As EVDs are directly

interacting with the system, the value, salience and expectancy are sufficiently high to attract drivers' attention. Contrarily, a UVDs perception of the changes induced by the presence of EVDs will depend upon allocation of attention to concurrent channels whose expectancy, value and salience is higher than the channels with the presence of EVDs. The probability of perceiving the changes induced by automated systems will increase if expectancy, value and salience are sufficiently high and if the effort is diminished. A range of variables can influence this such as the penetration rate of automated systems in traffic (expectancy), the conspicuity of automated vehicles (salience) or competing workload. Hence, based on the SEEV model, the four factors should be carefully analysed before designing an experimental study in order to draw UVDs driver on the changes induced by EVDs.

2.4 Car-following task

Before studying the effect of tightly spaced vehicles in a platoon on the THW of UVDs, it is important to understand the processes of car-following. First of all, car-following is a rather unusual driving behaviour happening when drivers are constrained in their velocity by a lead vehicle (LV) that is driving at a smaller velocity. Generally, following vehicles (FV) will attempt to overtake slower vehicles and must have a good reason if not doing so. The contrary of following is free driving when drivers have free choice over vehicle velocity (within the constraints of vehicle performance, handling and possible legal restriction). However, the threshold between these two states is indistinct. Vogel (2002) found that in an urban area two vehicles are linearly independent for THW of up to six seconds but Fastenmeier & Gstalter (2007) put the limit at two seconds without specifying the road type. An important part of car-following consists of maintaining a safe distance to the vehicle ahead.

A bank of research focuses on the driving parameters used by drivers to regulate the distance and on factors affecting these parameters. Another line of research explores how drivers accomplish this task and a variety of models that shed light on the mechanisms of car-following have been developed. This chapter outlines these two research lines.

2.4.1 *Safety margins*

The sensory input that underlies control actions in the driving task is primarily visual. Drivers have to monitor the environment continuously to read traffic signs, detect any obstacles in their path and, especially in a following situation, drivers have to track the vehicle ahead and keep a safe distance in order to avoid rear-end collision. The following chapter discusses two distance parameters that are used by drivers in a car-following task: time headway (THW) and time-to-collision (TTC). Time-to-collision (TTC) is a parameter informing about the criticality of a situation and THW is a safety margin (Vogel, 2003). Thus, THW reflects a tactical choice of drivers in relatively stable car-following situation whereas TTC reflects the criticality of a situation.

2.4.1.1 *Time headway*

Generally, the distance between two objects is measured in metres but in a dynamic situation, it is important that a distance parameter also includes information about speed and therefore the criticality of a situation. Indeed, a distance of 20 metres (~21.9 yards) between two vehicles may be considered acceptable when they are both driving at a speed of 30 km/h (18.641 mph) but unacceptable if they are driving at 200 km/h (124.274 mph).

Instead, the safety indicator THW is commonly used to estimate the safety of a driving situation. It has been defined as the elapsed time between the front of the LV passing a point on the roadway and the front of the FV passing the same point (Evans, 1991). The time headway is a time scale (s) measured by dividing the distance (m) through the speed (m/s):

$$\text{THW (s)} = \text{distance (m)} / \text{speed (m/s)}.$$

In many countries, legislation makes use of THW to determine a safe following behaviour. In the UK, the Driving Standards Agency recommends that drivers should maintain a THW of at least two seconds when following a vehicle in the dry (DSA, 2011). In Germany, a rule of thumb recommends that drivers keep a distance in metres of “half the speedometer” (Bouska & Leue, 2009). At a speed of 100 km/h (62.137 mph), this results in a distance of 50m (54.7 yards) and thus a THW of 1.8 seconds. However, actual driving data shows that drivers tend to adopt much smaller

THWs. Ayres, Schleuning, and Young (2001) for instance found THWs varying between 1 and 2 s during rush hour traffic on a heavily commuted eight-lanes motorway between Silicon Valley and San Francisco, USA. Brackstone and McDonald (2007) reported based on data collected in the UK's motorways that 95.8% of the headways were below 2 s, 78.1% were less than 1.4 s 47.9% was less than 1 s and 29.2% less than 0.8 s. The authors add that close following has been observed in other European countries such as France and Germany. Evans (1991) suggested two reasons to explain why drivers tend to follow too closely: 1) in normal dynamic vehicle following, the relative speed between two vehicles may be close to zero, therefore providing a static, visual impression of actual momentum and 2) drivers imagine the sudden braking of the LV as a rare event.

From evidence in the literature, it emerges that adopted THW is an outcome of the interaction between individual characteristics and situational factors.

Individual characteristics

It emerges from the literature that three different individual characteristics (skills, personality and attributes) have a long term impact on drivers' choice of THW.

Van Winsum and Heino (1996) found that individual drivers follow a THW that is independent of vehicle speed. Indeed, the preferred THW was consistent within drivers across speeds of 40, 50, 60, and 70 km/h (24.9, 31.1, 37.3 and 43.5 mph). Van Winsum and Brouwer (1997) replicated one year later the same result with the same speeds. Van Winsum (1998) reported experimental evidence that the preferred THW is related to the drivers' braking performance and perceptual-motor skills. Hence, drivers who preferred to follow the LV more closely were more efficient in the control of braking, braked harder and adjusted the intensity of braking better to the criticality (as measured by time-to-collision, TTC) of the moment the LV started to decelerate, compared with drivers who preferred to follow at a longer THW. A study conducted by Taieb-Maimon and Shinar (2001) also showed that drivers are able to adapt their THW to the current speed of the vehicle. Although the headway adopted is consistent within individual drivers, they differ widely amongst drivers. A study conducted by Heino, van der Molen, and Wilde (1996) stressed the fact that each driver has a preferred THW: results showed a large increase in mental effort, measured as an increase in heart

rate variability, when drivers were asked to follow at headway smaller than their preferred headway.

Besides drivers' skills in adjusting their braking in response to the TTC, personality factors such as sensation-seeking (Zuckerman, 1979) appear to influence the choice of THW. Literature shows that high sensation-seekers hold smaller THW than low sensation-seekers (for review see Jonah, 1997).

Finally individual differences have been reported in adopted THW due to drivers' attributes such as age and gender (Evans & Wasieleski, 1983; Taieb-Maimon & Shinar, 2001).

Situational factors

Firstly, impairment factors can affect the preferred THW arising from causes such as time-on-task, intoxication or concurrent tasks concurring with the driving task. Fuller (1981) found a significant increase in THW by truck drivers after a 7 hour drive, accompanied by verbal reports of performance decrements, drowsiness and exhaustion. Thus, the increase of safety margins might reflect a compensatory adjustment that is related to fatigue and aversion. Studies on drivers' intoxication through drugs, medication and alcohol are numerous. Smiley and Brookhuis (1987) found, for instance, that marijuana use increased headway while alcohol decreased headway. Task concurrent with driving such as a phone call, text messaging or a conversation with a passenger may impact drivers depending on the extent to which the secondary task competes with the driving task for similar resources (Wickens, 2002). Here again the amount of studies investigating the impact of secondary task on the driving performances is very large and just as an example, Brookhuis, de Vries and De Waard (1991) reported an increase in THW when using a car telephone whilst driving. The authors suggested that drivers are aware of the effects of task demands on their ability to detect a deceleration of a LV and adapt their THW accordingly.

Secondly, external factors have an impact on THW. In conditions of reduced visibility, such as fog, rain or night driving, drivers tend to drive at a larger THW (Van der Hulst, Rothengatter and Meijman, 1998). There is evidence that traffic density and flow influence following behaviour. Postans & Wilson (1983) reported a significant negative correlation between traffic density and THW ($r = -0.71$). The composition of traffic is also important: de Waard, Kruizinga, and Brookhu-

is (2008) demonstrated that directly after filtering into traffic with a large the proportion of heavy goods vehicles, variation in driving speed increased and minimum THW decreased. Thus, the size of other vehicles in traffic is meant to influence the following behaviour. Herman, Lam, and Rothery (1973) reported a smaller inter-vehicle distance between small cars than between large cars.

2.4.1.2 *Preferred and adopted THW*

The Risk Allostasis Theory (RAT) (Fuller, 2011) introduced in section 2.3.2 states that feelings of risk, as an indicator of task difficulty, are the primary controller of driver behaviour and drivers seek to maintain this within a preferred range. Based on the RAT, it is assumed here that the preferred THW represents actually a range of THWs drivers feel safe and comfortable with, based on their perceived capabilities to adjust the intensity of braking to the criticality of the situation. Within this range, drivers adopt a THW that is most appropriate within a given situation. Hence, a driver might keep a shorter THW when there is a high traffic flow on the road and a larger one in conditions of reduced visibility (e.g. night). Therefore, it seems that two constructs can be disentangled. On the one hand the preferred THW represents a range of THWs determined by drivers' perceived braking skills. The adopted THW, on the other hand, is the THW that drivers indeed adopt in a certain driving situation, which is depending on the current situational factors (e.g. visibility, other drivers, traffic flow).

2.4.1.3 *Time-to-collision*

Time-to-collision (TTC) is the time it would take a FV to collide with a LV if there is no evasive action. Hence the smaller TTC, the higher the criticality of the situation and if the relative velocity between a FV and LV is getting closer to null, TTC is getting infinite. If the velocity of the FV is smaller than the LV, TTC is negative.

Lee (1976) argued that drivers can estimate the time left until a collision is going to occur and are thereby able to control the braking process according to this visual information. Lee's theory is based on the concept of optic flow field introduced by Gibson (1950). Briefly, Gibson's concept states that visual perception is possible by means of the light reflected by surfaces. Thus, the light

reflected from the surfaces in the environment forms at the eye a densely structured optic array at a certain point of observation. Any motion induces a transformation of the optic arrays at the eye. If an optic array changes continuously over time, an optic flow field is formed by the differential changes of arrays induced by their position in space. Thus, the optic flow field affords information both about the layout of the environment and about the movement of the observer relative to it. If the distance between a FV and LV is closing, the array subtended by the LV is expanding on the retina. From this expansion results information about when a collision is going to occur if the velocity is constant. The time left until a collision occurs is calculated as follow:

$$TTC = \theta / \left(\frac{d\theta}{dt} \right)$$

where θ is the visual angle subtended by the LV at the eye of drivers of the FV and $\frac{d\theta}{dt}$ is the rate of change of the subtended visual angle (angular velocity). In line with Lee's theory, numerous studies have demonstrated that drivers are able to estimate TTC. A common feature of these studies is that movies are presented displaying a car-following situation from the drivers' perspective and showing an approach to a LV but with the participants in a stationary position. The movies are stopped during this approach and participants are asked to estimate when the vehicles would have collided. These experiments show a consistent finding that TTC is generally underestimated by drivers and that accuracy increases with small TTC values (Cavallo, Mestre, and Berthelon, 1997; McLeod and Ross, 1983; Schiff and Detwiler, 1979). Typically these experiments yield values of 0.6 for the ratio of estimated and actual TTC.

A similar laboratory study has been conducted by Hoffman and Mortimer (1994) but using film segments made from a FV approaching a LV, both vehicles were in motion. Results have shown that the accuracy of estimation of TTC was dependent on three independent variables: viewing time, relative velocity and headway between the vehicles. For an accurate estimation of TTC, the rate of change of the visual angle subtended by the LV must be above threshold value, which is about 0.003 to 0.004 radians per second. When the angular velocity of the LV is above this threshold, there is a linear relationship between the standard deviation (SD) of estimates and TTC. The SD of estimation increased with increasing headway and decreasing relative velocity. In contrary,

when the angular velocity is below the threshold, information about spacing changes of the vehicle during the viewing time may be used to infer relative speed and hence TTC. The “just noticeable difference” (JND) for changes in subtended visual angle has been reported to be about 10% the initial angle. There is evidence in the literature that there is variability between drivers in estimation of TTC with determining factors such as level of expertise (Cavallo & Laurent, 1988) and age (Hoffmann, 1994).

2.4.2 Car-following models

Before examining the distances held by drivers during car-following, it is important first to understand how car-following is undertaken. Many car-following models have been developed to understand and reproduce drivers' following behaviour as reviewed in Brackstone and McDonald (1999). Criticisms have been raised toward car-following models because the psychology of drivers is neglected as inter- and intra-individual differences is considered as an error (Boer, 1999; Ranney, 1999).

2.4.2.1 Gazis-Herman-Rothery model (GHR)

The car-following model from the General Motors Group (Chandler, Herman, and Montroll, 1958) represents probably the most studied model class (Brackstone & McDonald, 1999). The GHR model is based on the simplistic idea that the follower's acceleration is proportional to the speed of the follower (Brackstone & McDonald, 1999). The relationship between a leader and a follower is characterised as stimulus-response type of function, with the stimulus being the relative velocity and the response the acceleration or deceleration of the FV. Specifically, the acceleration of the follower at time t is calculated as:

$$a_n(t) = \alpha \cdot v_n^\beta(t) \cdot \frac{(v_{n-1}(t-T) - v_n(t-T))}{(x_{n-1}(t-T) - x_n(t-T))^\gamma}$$

where v_n is the speed of the vehicle n (m/s), x_n is the position of the vehicle n (m), a_n is the acceleration of vehicle n (m/s²) and T is reaction time (s). $\alpha > 0$, β and γ are the constants to be deter-

mined. Many investigations have attempted to find the optimal constants as review by Brackstone and McDonald (1999).

2.4.2.2 *Action Point Models*

As described by Brackstone and McDonald (1999) in their thorough review of car-following models, the main idea of psychophysical models (or action point models) is that car-following is controlled by the presence of perceptual thresholds that serve to establish a range within which drivers of the vehicle would be unable to notice any change to their dynamic conditions, and would seek to maintain a constant velocity. This model approach was triggered by Michaels (1963) and Todosiev (1998) who first raised the idea that car-following is controlled by the presence of perceptual thresholds. Further, in order to understand parameters used intrinsically by drivers to control a safe distance in a car following situation, several studies investigated drivers' sensitivity to detect visual changes using mainly psychophysical methods (Evans and Rothery, 1977). Psychophysical research investigates the relation between physical stimuli, S , and psychological response, R , where $R = f(S)$ (Stevens, 1958). The results of this research have generally been incorporated in psychophysical models of car-following or action point models, based on perceptual thresholds. Thresholds were first determined and integrated into a model at IfV Karlsruhe in Germany, the MISSION model of Wiedeman and Reiter (1992). Another famous model based on this approach is the VIS-SIM model, which is based on the MISSION model and Fritzsche's car-following model (Fritzsche, 1994) alongside with its variant used in the software tool, Paramics. In these models, driving behaviour is controlled by four perceptual thresholds namely a minimum (ABX) and maximum (SDX) threshold for desired spacing and threshold for positive (OPDV) and negative relative speed (CLDV) (Figure 9a). These points are referred to as so-called 'action-point'. The regime these thresholds define is depicted in Figure 9b: the vehicle approaches a slower vehicle, consequently drivers begin to decelerate until the individual threshold (ABX) and a null relative velocity is reached. Since drivers are not able to perceive infinitely small speed differences and to control the speed sufficiently well enough, they will decelerate below the current speed of the LV but will accelerate again when the threshold is reach (OPDV). But then they will accelerate over the current

speed of the LV and will decelerate again when the threshold (CLDV) is reached. The result is a spiralling effect as shown in Figure 10.

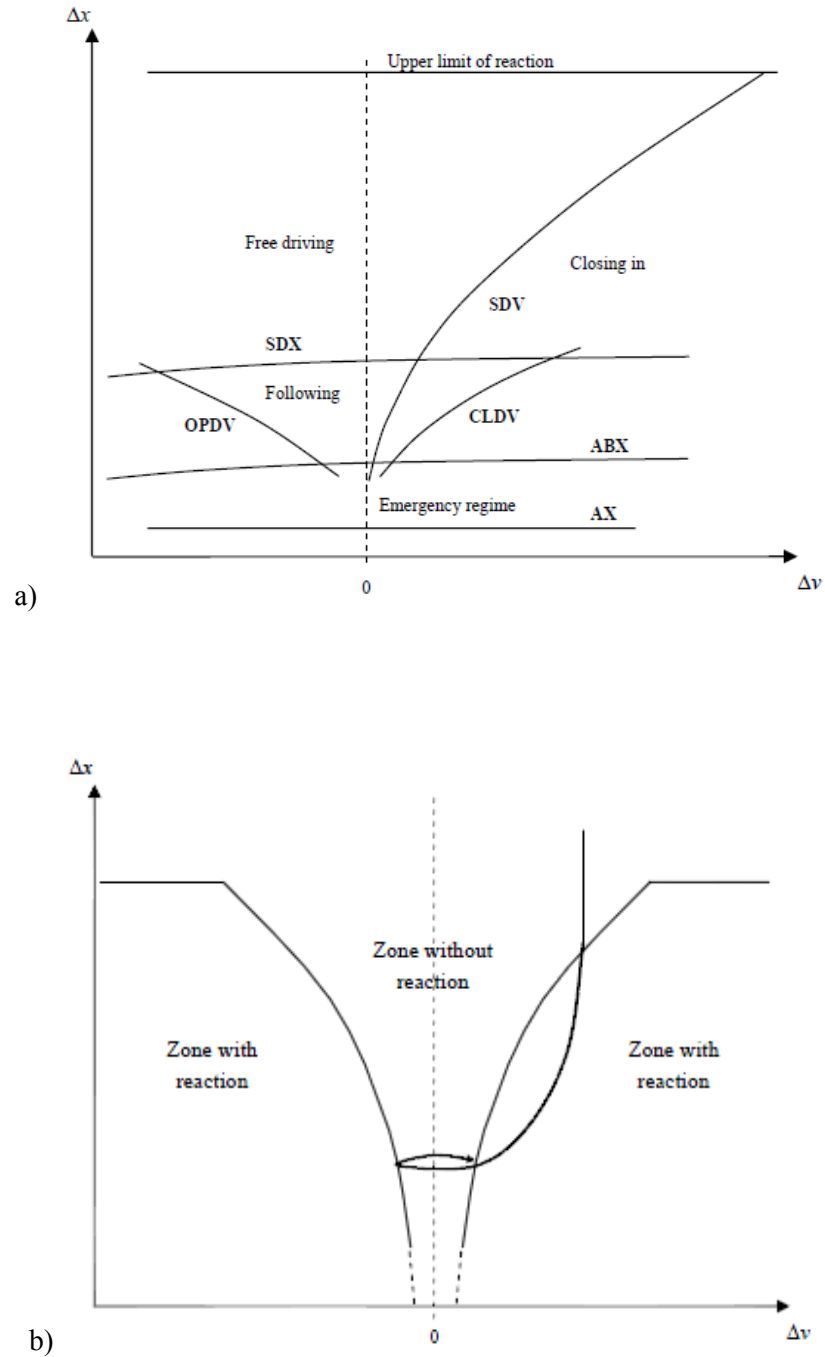


Figure 9 Threshold of the Action Point Models and process of following behaviour in action point model (with Δx for space headway and Δv for speed difference) (source: Olstam and Tapani, 2004; according to the model presented in Wiedeman and Reiter, 1992)

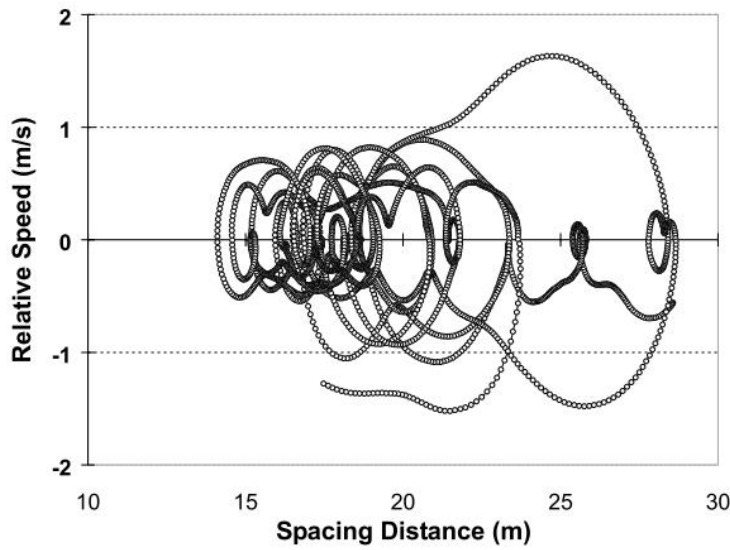


Figure 10 A typical 'close following spiral' (Brackstone et al., 2002)

This model can be regarded as a good step toward the integration of human elements in car-following models but still, it does not give enough insight into psychological variables influencing car-following behaviour. Indeed, Brackstone, Sultan and McDonald (2002), found in their analysis of naturalistic data collected on a UK motorway a large variation in the position of action points.

2.4.2.3 Van Winsum model

The model from Van Winsum (1999) has been developed in response to engineering models presented in Brackstone and McDonald (1999) and incorporates a variety of drivers' individual attributes:

$$D_p = t_p \cdot v_i$$

D_p is preferred distance in meters, t_p is preferred THW in seconds, and v_i the speed of drivers in m/s. t_p depends on drivers' skills but also on drivers' state, visual conditions, mental efforts and attention.

The model postulates that as long as the distance to the LV is larger than D_p , there is no reason to accelerate and how fast drivers are accelerating depends only on their motivation. However when drivers are close enough to the LV and the distance is smaller than D_p , drivers will initiate a decel-

eration. The distance D_d drivers decide to decelerate is equal D_p minus the distance at which drivers detect a difference in D_p . Drivers must perceive a change of the visual angle of the LV, which must be at least about 10%. This JND ('just noticeable difference') depends from the distance to the LV. The distance at which drivers decide to decelerate is:

$$D_d = \frac{W}{(\tan(1 + g) * a \tan (W / D_p))}$$

with W standing for the width of the LV in meters and g is the Weber fraction for JND in visual angle (10%).

Thus, this model uses the concept of perceptual threshold introduced action point models but it only addresses one part of car-following, namely negative acceleration when D_p is exceed. Van Winsum (1999) noted that '*there is no safety-related reason for the drivers to accelerate until D_p is reached*'. Thus, the author does not consider the following behaviour as a controlling process to maintain a preferred THW within two perceptual threshold as advanced by Brackstone and McDonald (1999).

2.5 Summary of the literature review

There is a high interest in the development of ADAS and ultimately automated driving as both are anticipated to bring about significant improvement in fuel consumption, traffic flow, safety and convenience of the driving task (section 2.2.1). Different types of automated systems have been developed and implemented in cars or are still in development, each covering an aspect of the complex driving task (section 2.2.2). Some of the systems are already actively intervening in the control of the vehicle (section 2.2.3), showing that the grouping of all these capabilities makes automated driving possible (section 2.2.4) and it is also a manifestation of the gradual introduction of automated driving.

However, concerns have been raised in the research community, which have been encapsulated in a prominent report from the Organisation for Economic Co-operation and Development (OECD), that drivers can react in unexpected ways to the introduction of safety measures and ADAS, a phe-

nomenon labelled “behavioural adaptation” (OECD., 1990) (section 2.3.1). Many underlying factors are responsible for behavioural adaptation (sections 2.3.2 to 2.3.4), making it hard to predict because it is influenced by a range of different factors which influence is still not fully understood, such as the influence of drivers’ personality (section 2.3.5). Also, research has focussed thus far almost exclusively on the behavioural adaptation of the driver as a result of direct interaction with automated systems neglecting any effect of the interaction with EVDs. Section 2.3.6 reviews research showing behavioural adaptation of drivers involved in a platoon. Drivers, who were engaged in platoons holding short THWs, kept short THWs in the subsequent manual drive. It has been interpreted that the cause for this behavioural adaptation is a shift in the frame of reference. After a platoon drive, ‘normal’ THWs appeared very large leading drivers to reduce the THW they would normally keep. In addition, section 2.3.4 shows evidence in the literature for influence on the driver of norms generated either by the direct or imagined presence of other drivers. As visual processes seemed responsible for behavioural adaptation of platoon drivers to short THWs in platoons and because the increasing amount of vehicles keeping short THWs in traffic might change the norm related to THW, it is postulated here that UVDs observing smaller THWs within platoons may also experience a shift in their frame of reference. Consequently, they may reduce their own THW, increasing the probability of a rear-end accident. This scenario highlights a potential risk that may emerge from the interaction between UVDs and EVDs in mixed traffic situation and suggests that this interaction should be investigated prior to the widespread introduction of ADAS that enables platooning.

Investigating the behavioural adaptation of UVDs as a response to the introduction of automated systems in traffic generates a range of different issues. Alongside with problems linked to the novelty of the research field, an issue resides in the fact that, de facto, UVDs are not directly interacting with automated systems, making a perception of changes induced by automated systems in traffic less evident (section 2.3.7). Another challenge is specific to any investigations on drivers’ THW as it requires understanding processes affecting drivers’ longitudinal control of the vehicles in a car-following task. One research line focuses on the safety margins used by drivers to regulate the distance informing about any useful parameters (section 2.4.1). The section highlighted the fact

that many different individual and situational factors influence drivers' following behaviour. The other line focuses on factors influencing drivers' longitudinal control of the vehicle in a car-following situation (section 2.4.2). However, it was stressed in the section 2.4.2 that car-following models were predominantly developed by engineers making the models unable to explain the inter- and intra-individual differences observed in car-following behaviour.

2.6 Conclusion of the literature review

The literature review presented how automated systems implemented in vehicles are increasingly taking over parts of the driving task providing an outlook on how driving situations in a near future will look like.

Given the disparity of autonomous vehicles, it is unsure yet which form will transpire but it seems that a common feature of automated driving will be short distances between vehicles. The advantages generated by short distances between vehicles consist essentially in a reduction in fuel consumption and in an increased road network capacity. It is foreseeable that the transition to automated driving will result first in a mixed traffic situation where UVDs will have to interact with EVDs. The prospect of this mixed traffic situation sparks a range of questions related to its practicality and safety for all road users. The focus of this work will be on behavioural adaptation of UVD to the vehicle behaviour induced by systems enabling automated driving. This work will specifically focus on the impact of the short distances kept by autonomous vehicles.

There is evidence in the literature showing that driving in a platoon alters perception of a safe driving headway to the car in front. It appeared that behavioural adaptation of platoon drivers to short THWs was here the result of perceptual mechanisms (section 2.3.6). As a results of social mechanisms (section 2.3.4), the perception of a safe THW could be altered by the UVD that is not directly engaged in a platoon but driving in its vicinity. It is unclear yet, whether the two mechanisms (perceptual vs social) will simultaneously lead to a behavioural adaptation of the UVD or if one will prevail on the other.

However, before investigating the mechanism responsible for the behavioural adaptation, the first objective of this work will be to find out whether behavioural adaptation of the UVDs to short THW in platoons exists.

To investigate BA of UVD to short time headway of platoons in the vicinity, four simulator studies were conducted. The common feature of all these studies was that participants were confronted to a car following task in the vicinity of platoons. The THW between the vehicles in platoons was either large or short. It was predicted that comparing participants' THW when driving next to a platoon keeping large THWs and a drive next to a platoon keeping short THWs will return significant differences.

3 METHODOLOGY

This chapter outlines the common methodology used in this work across the four experiments. Driving simulators represent an appropriate tool in this research for many reasons, as described below. However, the standard use of the simulator provides only information about the time headway (THW) drivers choose for a given situation i.e. their adopted THW. In this work greater insight was anticipated by also collecting data about individual drivers' preferred THW. Therefore, the psychophysical method of limits was applied to measure drivers' preferred THW and this method is described below.

3.1 Driving simulator

There are many reasons to prefer using driving simulators to field studies in research concerned with driving behaviour, as reported by Carsten & Jamson (2011). The main advantage of driving simulators is that they provide a relatively safe environment to investigate potentially dangerous situations such as the impact on driving performance of distraction such as mobile phones or of the effect of fatigue, drugs and alcohol. Moreover, the driving simulator enables investigations about technologies that are not available or only partly available on the market such as technologies enabling platooning. Also, the simulator allows a high controllability of the experimental trial. In contrast, many factors likely to affect the drivers' behaviour cannot be controlled in a field study (e.g. weather, traffic density, etc.). In a driving simulator, the experimenter can control unwanted influences on drivers such as weather conditions and other road users. Since the environmental and driving conditions are kept constant in a driving simulator, a smaller number of participants can be chosen without losing statistical power in comparison with a field study. Hence, driving simulators have a higher internal validity than field studies because the influence of confounding variables is reduced. However, this makes results obtained from a driving simulator difficult to generalise, resulting in a low external validity of the method.

Another advantage of driving a simulator is that performance data (e.g. speed, distance to next vehicle, lane lateral shift) are constantly available whereas it can be challenging to obtain the same data from a field experiment.

However, it is unclear yet whether it is an appropriate research tool to investigate any social aspects of the driving task. The influence of other drivers in the simulated environment might differ from the reality as participants will probably attribute any outstanding behaviour of other road users to the fact that behaviour is generated by a computer. In spite of this potential constraint, the simulator was selected as a research tool in this work because of all the other advantages in terms of costs, availability of technologies under investigation, safety for participants and high internal validity. A distinction can be made between low-, mid-, and high-level driving simulators (Weir & Clark, 1995). Low-level simulators typically consist of a PC, a monitor and simple vehicle control system. Mid-level simulators include advanced imaging techniques, a large projection screen, a complete vehicle with all normal controls and possibly a simple motion system. High-level simulators typically provide close to 360 degree field of view and an extensive moving base.

Modern driving simulators provide an increasingly realistic representation of the driving environment. Researchers therefore often assume that drivers will behave in a simulator as they behave on the real road when driving under similar situations (Blana, 1996). However, the simulator may induce a different behaviour than in reality. A distinction has to be made between absolute and relative validity: absolute validity refers to the correspondence between behaviour data in the simulator and in the real situation (e.g. same headway choice), whereas relative validity refers to correspondence in the direction or relative size of the effect of the measure taken in the simulator with reality (Blana, 1996; Harms, 1994; Kaptein et al., 1996). Relative validity is a critical requirement for a driving simulator to be a useful applied research tool as experimental studies deal with the effect of independent variables on dependent variables. Absolute validity becomes only a priority when the simulator is used as a training tool for specific situations, when behaviour learned in the simulator has to be transferred in the real world. Different forms of validity need to be maximised to enable a transfer between the simulator and the real world (Parkes, 2013).

Blana (1996) reviewed a large range of validation studies and concluded that relative validity is more commonly assured than absolute validity. Compared with other aspects of driving behaviour such as speed choice, lateral positioning and braking, the comparison between adopted THW in real and simulated environments has rarely been investigated. Duncan (1995) used TRL's driving

simulator (a previous version from the current one) and found that participants kept a greater THW in the simulator either when they were asked to maintain a “safe” or an instructed “fixed” time headway compared with a drive in a real car.

Table 3 summarises the advantages and drawbacks of field studies compared and simulator studies. In the present work, a driving simulator was used mainly because of the required implementation of systems that are not yet available on the market, but that could be easily recreated in a simulated environment. Additionally, due to the potential risky for behavioural adaptation, it was preferable to offer a safe environment to participants. A low-level simulator was used for the second experimental study because of the advantages in terms of cost and availability. However, following the outcomes of the study, it was decided to use a medium-level simulator in the subsequent studies. The issue, however, in conducting a trial in a simulator is that drivers might show behaviour they wouldn't necessarily adopt in a real drive. For example, drivers might feel less constraint about adopting a risky behaviour in a simulated drive than in a real drive.

Table 3 Assets and drawbacks of driving simulators and field studies

Method	Advantages	Drawbacks
Field study	<ul style="list-style-type: none"> - high external validity 	<ul style="list-style-type: none"> - low internal validity - high costs - not suitable for safety-critical studies - not suitable to measure systems that are not on the market already - difficulties in reliable, accurate measurement of vehicle behavior and control inputs
Simulator study	<ul style="list-style-type: none"> - high internal validity (controllability of variables) - low costs, decreasing depending on fidelity (high, medium, low) - Safe environment - Enable investigation of technologies not available on the market - Data easily available 	<ul style="list-style-type: none"> - low external validity - uncertainty about the suitability of the simulator to investigate social aspects of the driving task

3.2 Psychophysical method of limits

Driving simulators represent an appropriate tool to measure drivers' adopted THW, but the limits of preferred THW are not easily measurable in a conventional car-following study, as drivers rarely get close to their lower threshold of preferred THW.

One solution consists of using one of the methods of psychophysics to measure the thresholds of preferred THW. Psychophysics concerns the relation between physical stimuli, S , and psychological responses, R , where $R = f(S)$ (Stevens, 1958). Psychophysics generally refers to a class of methods that can be implemented to measure thresholds in general. The three methods traditionally used in psychophysics are the following (Stevens, 1957) :

- The method of limits consists of alternating two methods. In the ascending method of limits, a stimulus is presented at its low intensity and the intensity is gradually increased until participants report being aware of the stimulus. Contrarily, in the descending method of limits the stimulus is presented at a high intensity and the intensity is gradually decreased until participants are not aware of it anymore. In each case, the threshold is considered to be the level at which the stimulus has just been detected. The two resulting thresholds are averaged.
- In the method of constant stimuli and contrary to the method of limits, the various intensities of a stimulus are not presented in a gradual order but in a random order.
- In the method of adjustment, participants are instructed to regulate the intensity of a stimulus to the level where it just becomes aware to them. This procedure is repeated many times.

The method of limits consists in presenting various THWs in a linear order. The magnitude of changes between two time headways is therefore constantly kept at a minimum in the method of limits. Considering the delay required by the simulator to change THWs, it is of interest to keep the difference between two presented THWs at a minimum level, giving a benefit to the method of limits as compared to the method of constant stimuli.

In the method of adjustment, participants would get the instruction to display the smallest THW in the simulator they feel safe and confident with. However, evidence in the literature shows that THW in a car-following situation is not kept constant by the driver but instead THW oscillate around a certain value, which would create a noise around minimum preferred THW (section 2.4.2.). In the method of limits participants do not actively select the minimum preferred THW, which eliminates this noise. Because of the advantages of the method of limits in the context of simulator studies over the other two methods traditionally used in psychophysics, it was applied in the present study to assess the threshold of drivers' preferred THW. In the literature, psychophysical approaches have been employed in order to understand the visual parameters used intrinsically by drivers to control a safe distance in a car-following situation (e.g. Hoffmann & Mortimer, 1994;

Mortimer, 1972). The idea here is to extend the application of the method to assess perceptual thresholds of preferred THW. The method of limits as used in the context of this work is presented in section 5.3.5 and section 5.5 informs about the usefulness of a comparison between preferred THW and the one adopted during a simulated drive. Results in terms of validity and reliability of the psychophysical method of limits are presented in APPENDIX H.

4 FIRST EXPERIMENTAL STUDY

4.1 Introduction

Based on the evidence provided in the literature presented in Chapter 2, it is postulated that platoons formed by automated vehicles keeping short time headways (THW) could influence the behaviour of unequipped vehicle drivers (UVDs). Evidence is taken from research on behavioural adaptation of equipped vehicles drivers (EVDs) and it is argued that these findings could be reproduced in research on the UVDs. Thus far, experimental work on the behavioural adaptation of UVDs is scarce. Therefore, a study was first conducted to ensure that the research direction could be fruitful and to serve as a building block for the following experimental trials.

4.2 Hypothesis

This first experimental study investigated the influence of the THW adopted in a platoon of electronically coupled vehicles on the non-platoon driver nearby. The central hypothesis is that the non-platoon drivers will adapt their behaviour to the platoon, maintaining small THWs by reducing their own THW. More precisely, it is hypothesised that the influence of the presence of platoons maintaining short THWs will reduce THW for the UVDs.

4.3 Method

4.3.1 *Participants*

A total of 12 participants (6 males, 6 females) took part in the experiment and were all holders of a UK full driving licence for at least one year. They were all experienced simulator drivers from a pool of participants that the simulator team at TRL often invite for studies. In choosing experienced participants, the likelihood of initial learning effects or simulator sickness was minimised. The age of participants ranged between 24 and 35 years ($M = 28.1$ years, $SD = 3.7$ years), and the driving experience between 3 and 13 years ($M = 7.7$ years, $SD = 2.4$ years). Annual mileage ranged from 4000 to 18000 miles ($M = 11666$ miles, $SD = 3750$ miles). Participants were all TRL employees to

minimise recruitment costs for this first experimental study, however it is acknowledged that the use of such drivers may increase the likelihood that they will try to guess the aim of the study, which may subsequently influence their behaviour.

4.3.2 *TRL's driving simulator*

The first experimental study was conducted in TRL's medium-fidelity driving simulator (Figure 11). The simulator comprises a Honda Civic family hatchback right-hand drive car with a five-speed manual gearbox. The driving environment is projected at a resolution of up to 1920×1457 onto three forward screens to give the driver a 210° horizontal forward field of view. A rear screen provides a 60° rearward field of view, thus enabling normal use of all mirrors. Its engine and major mechanical systems have been replaced by an electric motion system that drives rams attached to the axles underneath each wheel. These impart limited motion in three axes (heave, pitch, and roll). A stereo sound system provides simulated engine, road, and traffic noise. The driving simulation is generated by SCANeR Studio 1.1 software (OKTAL). The experimenter runs and monitors simulations from a control room, which is located adjacent to the simulator room. An intercom system enables two-way communication between the experimenter and participant. Each of the simulator visual channels is presented on computer screens in the control room (Figure 12) and the experimenter can also monitor participants by means of a camera mounted inside the vehicle.



Figure 11 TRL fixed-base driving simulator



Figure 12 TRL driving simulator: control room

4.3.3 *Driving environment*

The type of road presented in this study was a three-lane motorway with gentle curves. The landscape was flat and wide open with trees in the surrounding. The two carriageways were separated by a double crash barrier in the middle. There were some vehicles travelling in the opposing carriageway but no traffic on the participants' side of the road apart from the lead vehicle and the vehicles within the platoon in the experimental conditions.

4.3.4 *Experimental design and procedure*

Many external factors within the simulation could be manipulated to create a favourable context for distance adaptation: behaviour of the lead vehicle (LV) (e.g. acceleration, mean velocity and variability of velocity), exposure time, the frequency of exposure (short-, medium- and long-term effect), conspicuity of platoon vehicles (i.e. large or small vehicles), platoon length, penetration rate and aim of the drive. In this first experimental study, these factors were held constant to focus on the manipulation of THWs maintained by platoons.

The design of the experimental study was composed of three drives: two experimental conditions and a baseline. In one condition the vehicles in the platoon maintained a THW of 0.3 s (condition THW03) and in the other 1.0 s (condition THW10) (Figure 13). The THW was the only difference between the two conditions. The THWs used in this experiment are the same as the ones used by

Skottke (2007). She did not justify the selection of these THW but it can be hypothesised that 0.3 s represents a “short” THW and 1.0 s a “normal” one. The number of vehicles in the platoon was thus different in order to maintain the same platoon length. Vehicles in the platoons all travelled at 110 kph (68.4 mph).

A within-subject design was selected because it reduces the amount of error arising from natural variance between individuals, thereby reducing the number of subjects required to achieve the same statistical power of results. Participants were instructed to follow a lead vehicle (a red Citroen C3) in each of the drives to allow the analysis of adopted THW over time (APPENDIX B). To make this scenario feel more realistic, they received the following instruction:

[...] “Your task is to follow a lead vehicle. Imagine that you are invited for a birthday party and you don’t know the route. A friend of you is invited for the same party and knows the route. He is driving in front of your car so that you can follow him. Thus, don’t lose track of him!” [...]

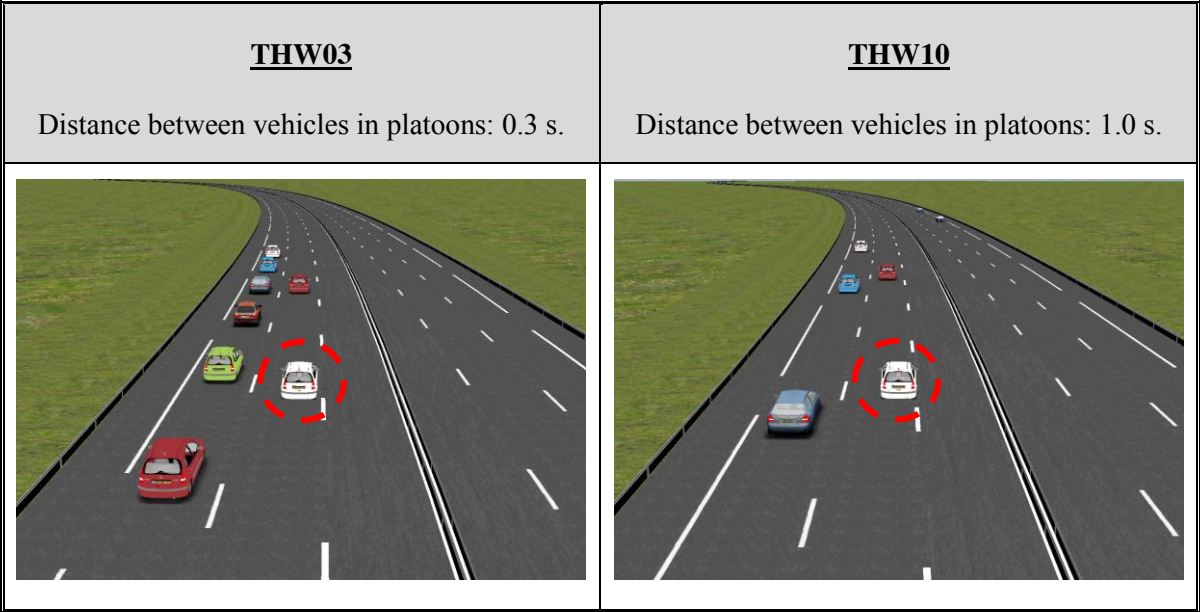


Figure 13 Screenshot of the simulator environment showing the participants’ vehicle (in a red circle) and lead vehicle in the middle lane and the platoon with time headway of 0.3 s (in condition THW03) and 1.0 s (in condition THW10) in the left lane.

Participants received no information about the presence of a platoon and were not informed about the purpose of the study to avoid the generation of expectations. The lead vehicle had a constant speed of 110 kph (68.4 mph), close to the UK legal speed limit on the motorway (70 mph) and was therefore permanently driving next to the platoon.

To control for any order effects, the order of presentation of platoon THW was counterbalanced between participants. The dependent variable consisted of the THW adopted by participants. In an initial baseline condition, participants drove on the slowest lane (the left lane in the UK) and there were no other vehicles present on the road other than the lead vehicle. This baseline was a control condition to assess their preferred THW without the effects of other drivers. Each drive lasted for 11 minutes, whereby the first minute of each drive was not included in the data analysis because it was the time needed for the vehicles in the platoon to settle to their predefined THW. Between each of the two drives, there was a short break. In total, the experiment took approximately 40 minutes for participants to complete. Table 4 shows an overview of the study design.

Table 4 Experimental design of the first experimental study

<u>1st Drive</u>	<u>2nd Drive</u>	<u>3rd Drive</u>
Baseline	THW 03	THW 10
	THW 10	THW 03
11 minutes	11 minutes	11 minutes

Before the trial, participants completed a demographic questionnaire (APPENDIX C) and were also asked to sign two exemplars of a consent form (APPENDIX A): one was kept by the participant and the other was archived by TRL. Participants were asked to read the instruction very carefully (APPENDIX B) and if they had no questions, the trial could commence. After having completed the study, participants were debriefed about the purpose of the study and the potential behavioural adaptation that may have occurred (APPENDIX D). They were told that they should drive carefully and keep a safe distance on their way home. Participants received £10 for their participation. The procedure for this experimental trial was approved by TRL's internal ethical committee.

4.3.5 *Measures*

Driving and environment parameters were synchronously collected at a frequency of 20 Hz. The driving simulator enables the collection of a range of driving parameters such as the speed, acceleration, position and distance to the next vehicle. The variable of interest here was the THW. THW is calculated as follows: distance to the next vehicle [m] / speed of the driven vehicle [m/s]. The distance to the next vehicle was measured by means of the cartesian distance between the front of the participant's vehicle and the rear of the lead vehicle. Ideally, the distance to the lead vehicle would have been measured along the road from the front of the "ego" vehicle (vehicle driven by participants) to the rear of the lead vehicle. The distance parameter will be corrected for the following studies.

A mean value was calculated for each participant from the data collected throughout the trial. Therefore, mean THW reflected behaviour that was adopted throughout an entire drive and was considered an indicator for changes in drivers' tactics. From the THW, the minimum THW for each participant in each condition was calculated to indicate the risk taken by drivers in the driving tasks. In addition, the percentage of time spent under the critical threshold of 1 s was calculated throughout each of the conditions. The value of 1 s has been identified in literature as a critical value under which following behaviour is considered as unsafe (see, for example, Fairclough, May, and Carter, 1997).

4.3.6 *Analysis*

Data analysis was carried out with the statistical software package IBM SPSS 19. A related t-test was used to compare the THW in two platoon conditions. Before computing the t-test, the following assumptions were verified:

- The normal distribution of the difference between scores was verified by means of the Kolmogorov-Smirnov test.
- Data were measured at least at the interval level, meaning that data are measured along a scale along the whole of which intervals are equals.

4.4 Results

The descriptive statistics of the three parameters (Mean THW; Min THW; % below 1s) are displayed in Table 5 for each condition. It emerged from the descriptive analysis of the data that participants adopted a different behaviour in the baseline as compared with the platoon conditions.

Between the two platoon conditions, the computed related t-test for the parameters mean THW and minimum THW showed no significant differences as displayed in Table 6.

As not all participants spent time below the critical threshold of 1 s, some values of the parameters are null. However, a dependent t-test was calculated and only participants showing a value not equal to 0 in both conditions THW03 and THW10 were considered. Results of a dependent t-test showed that the difference was marginally significant suggesting that participants spend on average more time under the critical threshold of a THW of 1s when driving in the vicinity of a platoon keeping short THWs.

Table 5 Descriptive statistics of mean THW, min THW and percentage of time spent under 1s (mean and standard deviation) for the two platoon conditions and the baseline.

Measurement	Mean THW		Min THW		% below 1 s	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Baseline	3.92	2.20	2.1	1.14	7.71	26.30
THW03	1.65	.94	.91	.47	30.87	29.75
THW10	1.53	.54	.93	.38	19.25	30.52

Table 6 Results of the independent t-test on mean THW, minimum THW and percentage of time spent under 1s

Measurement	t	df	<i>p</i>
Mean THW	.64	11	.53
Minimum THW	-.17	11	.87
% below 1 s	2.14	7	.07

4.5 Limitations

An issue in this first experimental study was that THW was computed with Cartesian distances, which is the coordinate difference between two points. The Cartesian distance does not consider the presence of curves in the road course, which results in a loss of precision.

Another limitation of the first experimental study was that no opportunity was given to the participants for familiarisation with the simulator to assess their skills related to the motor control of braking. Previous studies demonstrated that it is crucial for the determination of THW that drivers know their braking skills in interacting with a specific vehicle (see section 2.4.1).

4.6 Discussion

Contrary to expectations there was a lack of significant difference in participants' averaged and minimum THW between the two platoon conditions. However, results also showed that participants spent a marginally significant higher amount of time below the critical threshold of 1 s in the condition THW03. The latest results are encouraging and suggest that modifications in the setting of the experimental trial could lead to a significant difference in the mean THW.

The finding that the average THW did not significantly differ may be explained by the small amount of time participants spent driving next to the platoon (10 minutes). It is possible that an increased exposure time and larger sample size may have resulted in larger effects with regard to behavioural adaptation as measured by the average THW.

Platoons seemed to have a significant effect on drivers as compared to the baseline condition where no vehicles were present. However, it is difficult to compare as the baseline was not included in the counterbalancing plan. It is therefore possible that learning effects affected the difference. An explanation for the clear difference in car-following behaviour between the platoon conditions and the baseline could also be that participants felt no inclination to follow at a shorter distance because they did not fear losing track of the lead vehicle since there was no other traffic present. To address these issues, further trials should add some traffic in the same way in the right lane. Furthermore, the baseline shall be introduced in the counterbalancing plan to make any comparison with platoon conditions possible.

Finally, another issue concerns the lack of parameters showing whether participants' change in car-following behaviour is an effect of the new norm established by platoons. It was discussed in the literature review (Chapter 2) that participants could reduce their THW as an effect of the new norm imposed by the THWs kept within a platoon. Participants could adopt a shorter THW than the one they would normally prefer just to match the behaviour of other drivers in the vicinity. A method therefore has to be developed to measure the THW participants would prefer to keep. Hence, it can be investigated whether the THW adopted is below the preferred THW as an influence of the short THWs maintained in platoons.

4.7 Conclusions

The lack of understanding about the conditions for emergence of behavioural adaptation by the UVDs makes the investigation of the effect a challenge. This difficulty is apparent in the first experimental study presented in this chapter as results show that not all indicators were sensitive to the treatment conditions. Nevertheless, the amount of time spent under the critical threshold of 1 s showed a marginal significance between the conditions. This hint in the pilot data that changes in THW could be caused out of UVDs is leading to a larger scale study.

5 SECOND EXPERIMENTAL STUDY: A CONFORMITY STUDY

5.1 Introduction

The introduction of platoons with short time headways (THWs) might shift the norm on THWs generally maintained by drivers on the motorway and in turn induce non-platoon drivers to reduce their adopted THW (mean and minimum).

The model of planned behaviour (TPB) (Ajzen & Madden, 1986) introduced section 2.3.4 with its extension (De Pelsmacker & Janssens, 2007) serve as a conceptual framework to predict a change in unequipped vehicle drivers' (UVDs) following behaviour. According to the TPB, behavioural intention represents one of the most important predictors of behaviour. Intention is in turn influenced by social norms, perceived behavioural control and attitudes. In the extended TPB additional norms have been specified (normative, descriptive and personal) to stress the influence of others on driver's behaviour.

Platoons with short THWs are due to be implemented on regular motorways without any separation from normal, unautomated traffic. The presence of platoons will therefore be direct, real and visible to the rest of traffic, which might change the descriptive norm influencing other drivers in the vicinity of a platoon. To conform to the descriptive norm set by platoons, UVDs might reduce their own THW. Usually, drivers adopt a THW from a range of preferred THWs they feel safe and confident with, which is depending on their perceived behavioural control (section 2.4.2.1). Nevertheless, to close the gap between their THW and those in a platoon, drivers might even adopt a THW that is below their perceived behavioural control. This effect would imply that their perception of perceived behavioural control and attitude towards THWs has changed too.

As a result, the minimum THW adopted by drivers when driving next to platoon keeping short THWs might be below the THW they would prefer to keep in a 'normal' driving situation, when there is no platoon keeping short THWs in traffic. Comparing UVDs' minimum adopted THW to the lower threshold of their preferred one (minimum preferred THW) would show whether drivers went below their limits as a result of platoons' influence. Adopted THW (mean and minimum) is easily measurable by means of a car-following study. Contrarily, the limits of preferred THW are

less easily measurable in a conventional car-following study as drivers rarely get close to the lower threshold of preferred THW. The psychophysical method of limits is designed to measure thresholds in general and has been applied in the present study to assess the threshold of drivers' preferred THW (minimum preferred THW). Comparing minimum adopted THW with minimum preferred THW will inform about whether drivers were prepared to keep a THW that is beyond their perceived behavioural control. If the results show that drivers adopting THWs shorter than the ones they would prefer, this would support the influence of social mechanisms in the behavioural adaptation of UVDs to short THWs kept in platoons.

Therefore, the second experimental builds up on the previous first experimental study (Chapter 4) but introduces a method to measure preferred THW. Another modification of the design used in the first experimental study comprised the assessment of some of drivers' personal characteristics and the introduction of a familiarisation drive.

5.2 Hypotheses and explorative questions

In two different simulated drives, participants were confronted with either a platoon maintaining short distances (THW = 0.3 s) or a platoon maintaining longer distances (THW = 1.0 s). It is assumed that participants will keep significantly shorter THW in the drive where they are confronted with platoons keeping short THWs.

- Hypothesis 1 (a): There is an influence of platoons maintaining short THWs on drivers' tactics. Non-platoon drivers adapt their behaviour to the short THWs maintained in a platoon by reducing significantly their mean THW.
- Hypothesis 1 (b): There is an influence of platoons maintaining short THWs on drivers' safety. Non-platoon drivers adapt their behaviour to the short THWs maintained in a platoon by reducing significantly their minimum THW.

It is an explorative question to see whether drivers are ready to adopt THW that is lower than preferred THW in the condition where platoons keep short THW. If minimum adopted THW meas-

ured in the simulated drives is smaller than minimum preferred THW measured with the psychophysical method of limits, the interpretation will be that drivers are taking a risk.

A psychophysical method of limits is implemented in order to measure drivers' minimum preferred THW and the aim is to compare it with the minimum THWs adopted by drivers in the simulated drives. Beforehand, it is necessary to verify that minimum preferred and adopted THW are two separate constructs.

Hypothesis 2 : There is a significant difference between minimum preferred and adopted THW. Furthermore, the present study is also exploring how personality is affecting behavioural adaptation. The personality traits explored here are those found to be correlated with certain behaviour patterns of the driving task as presented in Chapter 2 (section 2.3.5).

5.3 Method

5.3.1 Participants

To estimate an appropriate sample size to achieve adequate power, an a-priori power analysis for ANOVA with repeated measures was computed with the software G*Power 3 (Faul et al., 2009) using information from the first experimental study about the mean correlation between the repeated measures ($= 0.7$). Following convention, an alpha level of 0.05 and power of 0.8 was employed. Considering the lack of significant effects for the average THW in the first experimental study, the power analysis was run with a small effect size. When $f = 0.15$, the results of the power calculation indicated a recommended sample size of 45 and when $f = 0.2$, the result indicated 26.

A total of 42 participants took part in the experiment (21 males, 21 females) and all were holders of a full UK driving licence for at least one year ($M = 17.48$; $SD = 10.73$). Their age varied between 20 and 64 ($M = 35.93$; $SD = 11.26$) and their mileage between 2000 and 35000 miles a year ($M = 10369.05$; $SD = 6211.77$). All participants were recruited from TRL's participant database of local members of the public and had previously participated in driving simulator studies. As experienced simulator trial participants, the likelihood of initial learning effects or simulator sickness was minimised.

5.3.2 Apparatus

The low-level simulator (Figure 14) consisted of a flat table upon which a steering wheel and manual gearbox (Logitech G27) were mounted, offset to the right to replicate the typical UK driving set-up. Corresponding pedals (clutch, brake and accelerator) were located beneath the steering wheel under the table. A 55'' plasma screen (HITACHI 55PMA550) was placed behind the table. Participants were seated in front of the table on an office chair without wheels. The driving simulation was generated by SCANeR Studio 1.1 software (OKTAL). The driving performance data was recorded at a frequency of 20 Hz throughout each participant's drive. THW (s) was calculated as follows: distance to the lead vehicle (m) / speed (m/s). The distance to the lead vehicle was measured along the road from the front of the "ego" vehicle to the rear of the lead vehicle. Actual speed and the rev counter were displayed to the driver on the bottom of the screen. In this configuration, the experimenter was seated in the same room but a partition wall separated the experimenter from participants.



Figure 14 Set-up of the low-level simulator

5.3.3 Driving environment

To investigate the impact of short THWs in platoon on drivers nearby, research was carried out in the low-level simulator.



Figure 15 Example of a simulated road section used for the trial

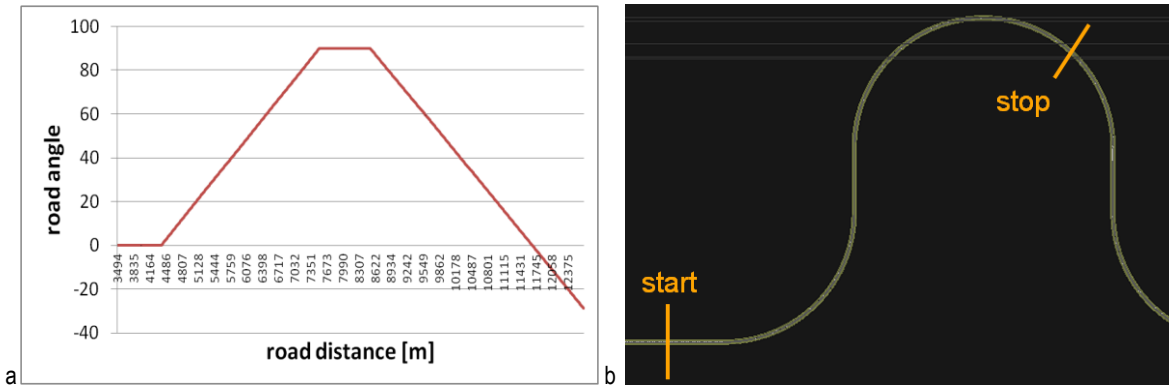


Figure 16 road angle (a) and road perspective from the top (b)

The simulated road environment consisted of a three-lane motorway (Figure 15) of a configuration typical of that found in the UK. The two carriageways were separated by a double crash barrier and a single crash barrier bordered the external boundary of the roadway. Trees were scattered on both sides of the motorway whilst occasional bridges and gantries were displayed over the motorway. According to Highway Code (2011), a road of this type has a speed limit of 70 mph.

The scenario started on a straight road segment, which was followed by a first curve and followed in turn by a second straight road segment and a second curve (Figure 16). The rationale behind a partly curvy road was to make the car-following task less monotonous as drivers had to work to control the lateral position of the vehicle. The length of the segment used for the purpose of the study was approximately 12.5 km (7.77 miles).

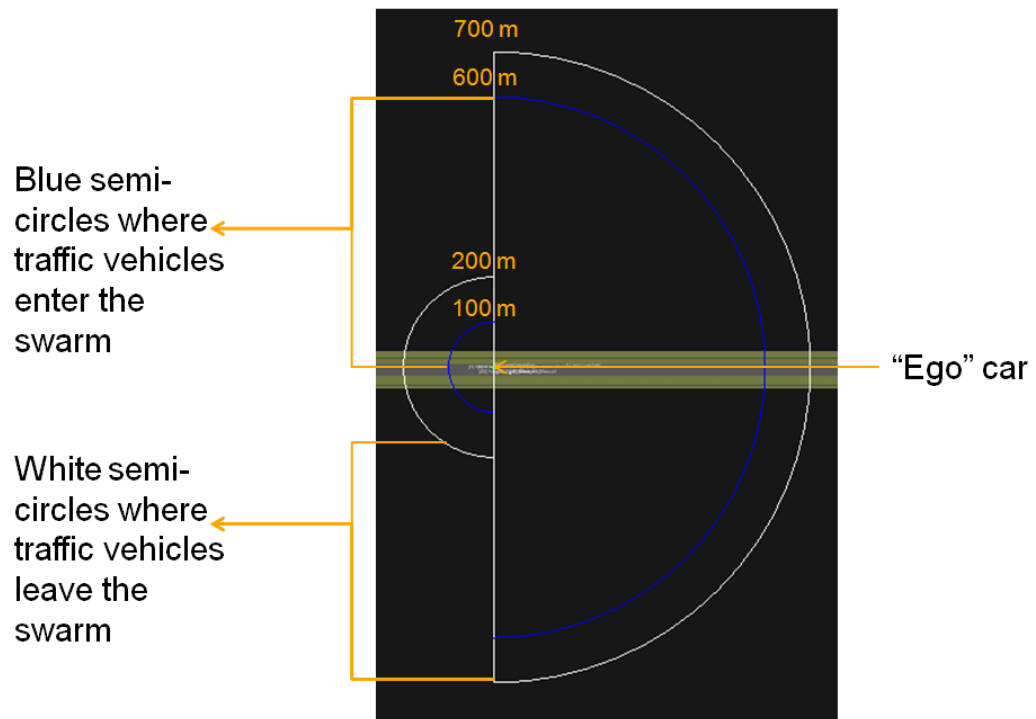


Figure 17 Four semi-circles limiting the swarm around the 'ego' car

In the simulated drives, traffic was generated by creating a swarm of vehicles around the 'ego' car (vehicle driven by participants) (

Figure 17). Characteristics of the swarm were governed by four semi-circles centred on the 'ego' car; two in the front of the vehicles and two behind. The radii of the semi-circles are adjustable (radii were selected in order to get the highest possible flow) and are respectively from the front to the back: 700 m, 600 m, 100 m, 200 m. Vehicles entered the swarm by the blue semi-circles and disappeared at the opposite white semi-circles. Once a vehicle belonging to the swarm vanished at a white semi-circle, it was regenerated at one of the blue semi-circle. Vehicles were disposed either on the same carriageway (only on the outside lane) or the opposite direction as oncoming traffic (on all three lanes). The swarm consisted of five vehicles driving at a speed of 160 km/h and kept at least a 'safe' THW of 2 s. Generally, the distance between two vehicles in the swarm tended to be larger. As the number of vehicles in the swarm was restricted due to computer performance, the speed was set high to increase the flow. The high speed of traffic vehicles in the outside lane was not perceived as unnatural in the simulator.

5.3.4 *Experimental design and procedure*

At the beginning of each trial, participants signed a consent form (APPENDIX A). Afterwards, they were introduced in the simulator and were asked to make the required adjustments (i.e. seat and mirrors) to minimise distraction during the trial. There were then first asked to fill in a demographic questionnaire containing questions about their age and driving experience (APPENDIX F) and secondly, they received written instructions for the trial (see APPENDIX E). If participants had no questions, the experimental study commenced.

The study alternated the evaluation of the adopted THW (simulator drive) under three different conditions (BL /THW03 /THW10) with the evaluation of the preferred THW (psychophysical method of limits) taking place after each of the simulator drives (Table 7). A repeated measures design was employed: each participant drove on the same simulated road under the two platoon conditions (THW03 and THW10) along with the baseline (BL) and underwent the evaluation of preferred THW after each of the simulated drive. The order of presentation of simulator drives was counterbalanced to control for any order effects. The drives for the psychophysical method of limits were also counterbalanced.

After having completed the study, participants were debriefed about the purpose of the study and they were informed that a carry-over effect from the expected behavioural adaptation in the simulator to the real world could occur (APPENDIX D). They were instructed to be aware of their distance and keep at least a THW of 2 s to avoid this effect. Finally, they received monetary compensation for their time and expenses and were thanked for their attendance. Each experimental session lasted for approximately 2 hours. The procedure of the experimental trials was approved by TRL's internal ethics committee.

Table 7 Overview of the study design (the orders of simulator drives and drives for the psychophysical method of limits were counterbalanced)

<u>Drive No</u>	<u>Method</u>	<u>Parameters</u>	<u>Time</u>
1	Familiarisation	-	≈ 5 min.
2	Psychophysical method of limits (familiarisation)	Preferred THW	≈ 5 min.
3	Simulator drive (BL /THW03 /THW10)	Adopted THW	6 min.
4	Psychophysical method of limits	Preferred THW	≈ 5 min.
5	Simulator drive (BL /THW03 /THW10)	Adopted THW	6 min.
6	Psychophysical method of limits	Preferred THW	≈ 5 min.
7	Simulator drive (BL /THW03 /THW10)	Adopted THW	6 min.
8	Psychophysical method of limits	Preferred THW	≈ 5 min.

5.3.5 Independent variables

Familiarisation

Prior to the experimental drives participants performed a familiarisation session in particular to get used to the braking characteristics of the simulator vehicle. As discussed in chapter 2, perception of one's own braking abilities are expected to be a determining factor of preferred THWs (Van Winsum, 1998). Moreover, braking abilities are linked to the vehicle's dynamics and therefore dependent on the vehicle model driven. It was therefore important that participants were able to familiarise themselves in order to judge what THWs they felt safe and comfortable with. In order to facilitate the familiarisation process, the scenario required participants to alternatively accelerate and decelerate. The lead vehicle (LV) decelerated from 57 to 0 miles in 5 s every 40 s approximately, reaccelerated straight after to 57 miles and kept the speed for another 40 s before decelerating again and so forth. Participants were asked to keep a safe and constant distance, which effectively required them to use the accelerator and brake in response to the LV's accelerations and decelerations. Par-

ticipants were asked to stop once they felt familiarised with the simulator. After the familiarisation session, the measurement procedure started.

Two different scenarios were used to measure the adopted THW (simulator drive) and preferred THW (psychophysical method of limits).

Simulator drives - adopted THW

In the simulated drive, participants were asked to follow a LV with the instruction to remain in the same lane as the LV throughout. As the simulator's limit to record THW data is 8 s, participants were explicitly asked to not leave too large a gap otherwise a message would appear on the screen (Figure 18, top left in red). Participants should not have felt restricted in their choice of THW as a THW of 8 s is a very large one (244 m at 110 kph). They were familiarised with the maximal authorised distance during a prior familiarisation drive so that none of the participants exceeded the limit during the experimental conditions. Participants were also instructed to stay in the same lane than the LV and a message was appearing on the screen when participants were shifting on an adjacent lane (Figure 18, top right in green).



Figure 18 Warning messages display over the simulated environment, reminding drivers to stay in the same lane and not too far from the LV (THW < 8 s)

To motivate drivers to follow the LV and make the scenario realistic in spite of both lane and distance restrictions, participants received following instruction:

[...] *“In an active drive you are asked to follow a red vehicle that is driving in front of you.*

Imagine that you are invited for a birthday party and you don't know the route. A friend of you is invited for the same party and knows the route. He is driving in front of your car so that you can follow him. So, don't lose track of the car.' [...]

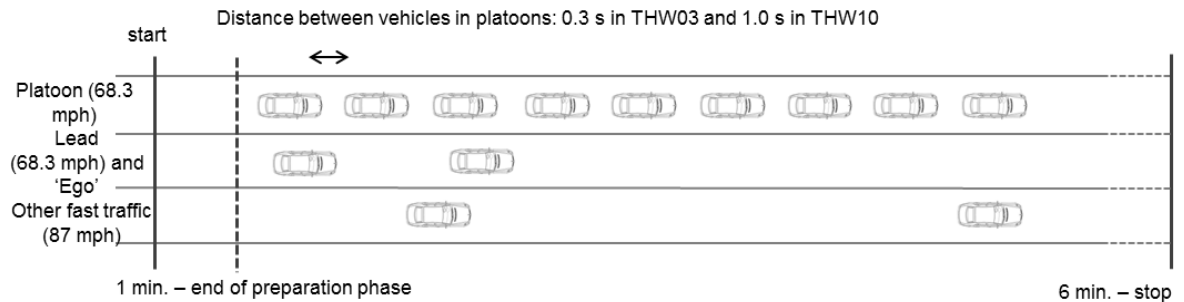


Figure 19 Schema of the study design in conditions THW10 and THW03

In two of the drives, a platoon of vehicles was assigned to the left lane maintaining either a short THW of 0.3 s (THW03) or a longer THW of 1.0 s (THW10). The LV was constantly driving next to the platoon and at the same speed (110 kph = 68.4 mph). In the baseline (BL) condition, there were no other vehicles present on the road other than the LV. This baseline was a control condition to assess preferred THW in the absence of other traffic. In all three drives, the 'ego' car and the LV drove in the middle lane with random traffic driving on the outer right (fast) lane in order to make participants realise that other cars could move into the gap ahead if this was too large. Figure 19 summarise the procedure to measure the adopted THW. Each drive lasted for 6 minutes, whereby the first minute of each drive was not included in the data analysis because it was considered as a run-in into the trial. There was a trade-off regarding the duration of the trial: in the course of a prolonged drive, THW is progressively increasing, thus a short trial time would be preferable. However, perhaps a short exposition time is not sufficient to get a distance adaptation. Because the driving task is monotonous in this trial, a short exposition time has been selected but there is a risk that it might not be sufficient.

Psychophysical method of limits - preferred THW

The measurement of the preferred THW took place on the same route with the exception that there were no other cars present but the LV. At the very start of the drive, the ‘ego’ vehicle accelerated automatically up to 70 mph and the simulator took over lateral and longitudinal control of the vehicle but participants were asked to keep their hands on the steering wheel as if they were driving normally. Based on the psychophysics method of limits (Fechner, 1889), participants were exposed to a set of increasing THWs, starting from a very short THW (0.1 s) (Figure 20). After a THW was presented for 5 s, the screen was blanked and participants were asked to respond ‘yes’ if they would normally adopt this THW or whether it was ‘too short’ or ‘too large’. Consecutive THWs increased with steps of 0.1 s. The screen was blanked for 5.0 s, which was enough time for participants to respond. Afterwards, the incremented THW was displayed for another 5.0 s. The presentation of THWs was stopped once the preferred THW was reached. The same process was repeated with a set of gradually decreasing THWs starting from a very large THW (2.5 s) (Figure 20). The presentation of THWs was stopped at the point at which the THW no longer represented drivers’ preferred THW. The presentation of the set of increasing and the set of decreasing distances was counterbalanced and the results from both sets were averaged. As the result in each set represented a threshold, which was the lowest THW that participants would accept, the output of the THW assessment represents in fact a minimum preferred THW.

Before the experimental trials started, participants were first familiarised with the method.

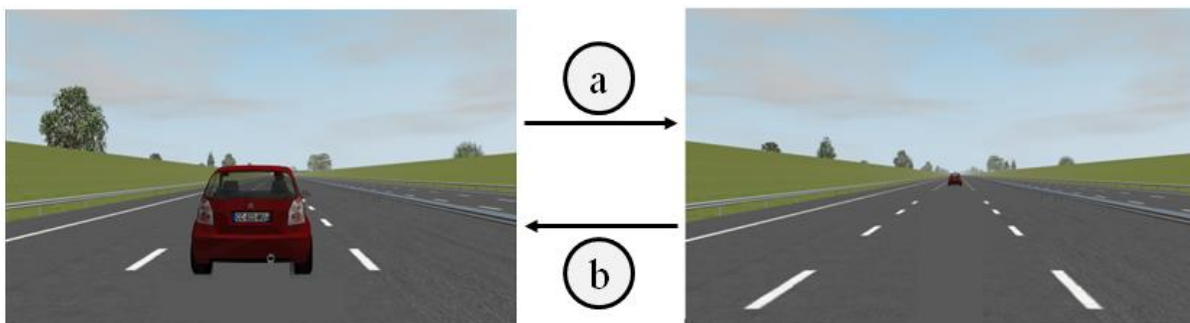


Figure 20 The psychophysical method of limits implemented for the assessment of preferred THW includes the presentation of a set of (a) increasing THWs starting with a very small THW (0.1 sec) and (b) decreasing THWs starting with a large THW (2.5 sec).

5.3.6 Dependent variables

Figure 21 represents a structure of the dependent variables that were considered for the statistical analysis. The dependent variables can be separated in two categories: performance and subjective data.

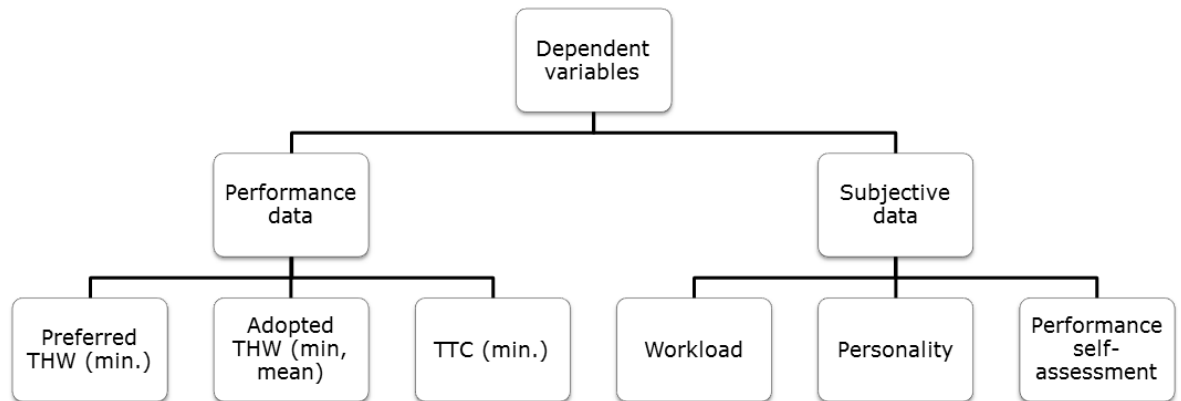


Figure 21 Structure of dependent variables considered for the data analysis of the second experimental study

Performance data encompasses minimum preferred THW as an output of the psychophysical method of limits developed for the purpose of the study and adopted THW. In the simulated drives, driving performance data were recorded at a frequency of 20 Hz throughout each participant's drive. THW (s) was calculated as follows: distance to the LV (m) / speed (m/s). The distance to the LV was measured along the road from the front of the 'ego' vehicle (vehicle driven by participants) to the rear of the LV. Mean THW in stable car-following situation (LV has a constant speed) is assumed to be an indicator for tactical adaptations of driving behaviour to situational factors (Vogel, 2003) and minimum THW was computed as an indicator for criticality. Minimum TTC is also an indicator of criticality as short TTC indicates a near accident (Vogel, 2003).

If THW is plotted over time, a sinusoidal function emerges. It is important to remember that, as the lead vehicle was constantly driving at the same speed, the fluctuation in THW can only be attributed to the following vehicle. Drivers did not maintain THW at a precisely constant value but instead THW fluctuates around the mean value. This fact is illustrated in Figure 22 with the data from one

participant showing the typical oscillation of THW. Therefore, a mean THW was calculated as a mean value for each participant.

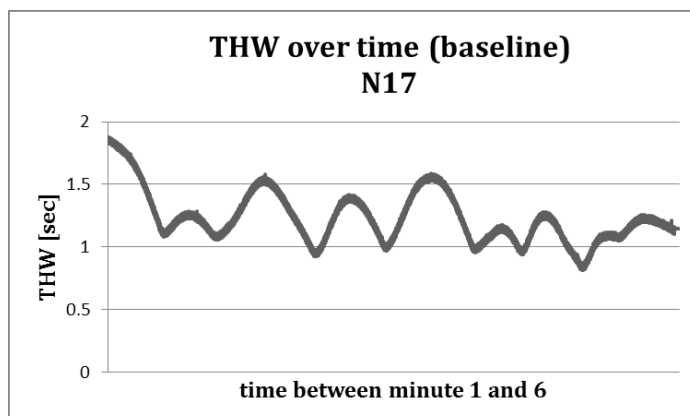


Figure 22 Data sample for one participant as an example for THW data when plotted over time

Subjective measures included workload measurement, performance rating and personality measures. After each simulated drive, mental effort ratings were collected using the National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart & Staveland, 1988) to assess whether increased workload was associated with changes in traffic. The NASA-TLX is composed of six different subscales rated on a 0-100 scale: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration.

Furthermore, subjective ratings of driving behaviour (speed and distance) were collected in order to test whether participants thought their performance changed throughout the different drives. The rating used a 7-point Likert scale (1= very close, 7= very far).

After each psychophysical method of limits, participants were asked to fill in personality and cognitive style questionnaires in an attempt to establish a relationship between drivers' distance behaviour and personality factors (APPENDIX F). The assessed personality traits were found to be correlated with certain behaviour patterns of the driving task as presented in Chapter 2 (section 2.3.5).

- One part of the questionnaire used the same questionnaire than Ulleberg and Rundmo (2003): four of the scales are facets from the NEO-Personality Inventory (Costa et al., 1992) (shown in brackets): Anxiety (Neuroticism), Anger (Neuroticism), Excitement-seeking (Extraversion) and Altruism (Agreeableness) and the items were selected from the

International Personality Item Pool (Goldberg et al., 2006). The normlessness construct was measured with the Normlessness scale (Kohn & Schooler, 1983), which consists of four items.

- Locus of Control was measured with a scale specifically dedicated to driving behaviour (Montag & Comrey, 1987),
- The driver behaviour questionnaire (DBQ) (Lawton et al., 1997) (as presented chapter 2.3.5),
- The Group Embedded Figures Test (GEFT) was administered to measure Witkin's (1962) concept of field-dependence/independence (FDI).

5.3.7 Analysis

For every dependent variable, the overall main effect was analysed by using one-way ANOVAs for repeated measures. Before running ANOVA for repeated measures, assumptions were verified. Greenhouse-Geisser (1959) correction was applied if the assumption of sphericity was violated. Furthermore, pairwise comparisons were computed and the p -values were corrected according to the Bonferroni method. A significance level of $p < .05$ was adopted for all statistical tests.

5.4 Results

5.4.1 Results obtained with the psychophysical method of limits

A 2×3 factorial ANOVA was run with following within subjects factors: traffic conditions (BL, THW03 and THW10) and the method used to measure minimum THW (simulator drives vs psychophysical method of limits). There was a significant effect of the driving condition on drivers' THW [$(F_{(2, 82)} = 12.10, p < .05, \eta_p^2 = .23)$] as well as a significant difference between the THW types measured [$(F_{(1, 41)} = 6.38, p = .02, \eta_p^2 = .14)$]. Planned contrasts revealed that traffic significantly increase THW as compared to a baseline drive with no traffic (BL vs platoons) [$(F_{(1, 41)} =$

16.10, $p < .05$, $\eta_p^2 = .28$) and they also reveal a significant difference between the two platoon conditions (THW03 vs THW10) [$F_{(1, 41)} = 6.38$, $p = .02$, $\eta_p^2 = .14$].

Figure 23 shows that the (minimum) adopted THW was always higher than the (minimum) preferred THW, however adopted THW was close to the preferred THW in THW03 and to a less extend in THW10. Dependent tests with Bonferroni correction were used to compare minimum adopted and preferred THW in each traffic condition. There was a significant difference between the adopted and preferred THW in condition BL [$t_{(41)} = -3.44$, $p < .05$, $r = -0.23$] but no significant differences were observed in conditions THW03 [$t_{(41)} = -.88$, $p = .39$, $r = -0.05$]. In THW10, the difference is close to the significant level ($\alpha = 0.0167$) but do not reach it [$t_{(41)} = -2.07$, $p = .04$, $r = -0.11$].

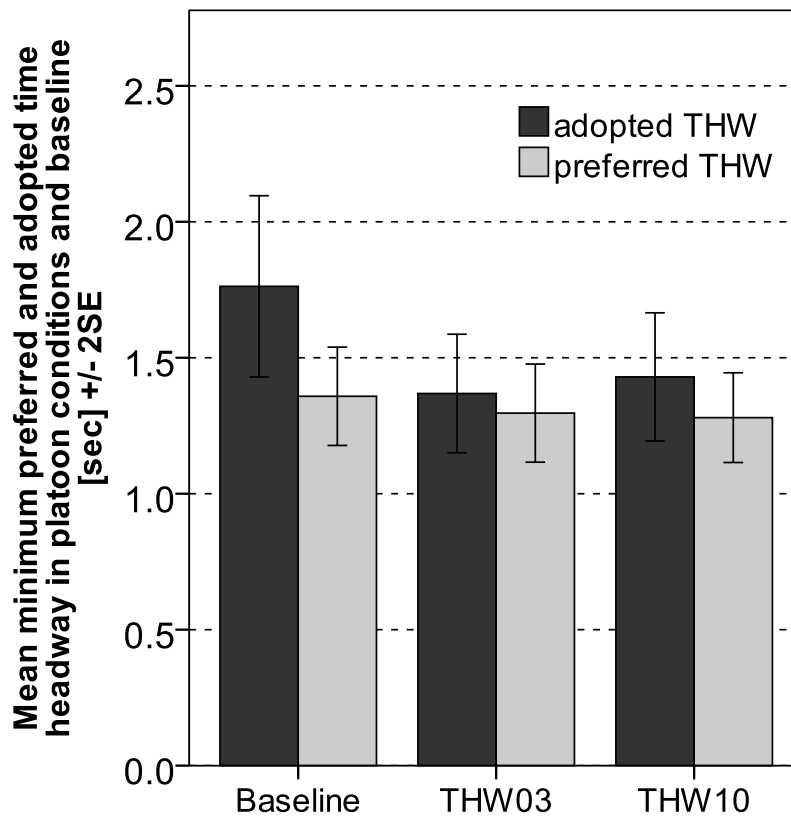


Figure 23 Averaged minimum preferred and minimum adopted THW and standard error (+/- 2SE) in the three traffic conditions (BL, THW03, THW10) (N = 42)

5.4.2 Results of simulator drive

Time headway

The analysis of minimum THW conducted above has shown an expected tendency despite a lack of significance: the minimum adopted THW is shorter in condition THW03 than THW10. Similar results are observed for the mean THW (Figure 24): the mean value is higher in the baseline where there was no traffic present ($M = 2.61$; $SD = 1.37$). There is a small difference between THW03 ($M = 2.04$; $SD = .99$) and THW10 ($M = 2.12$; $SD = .93$).

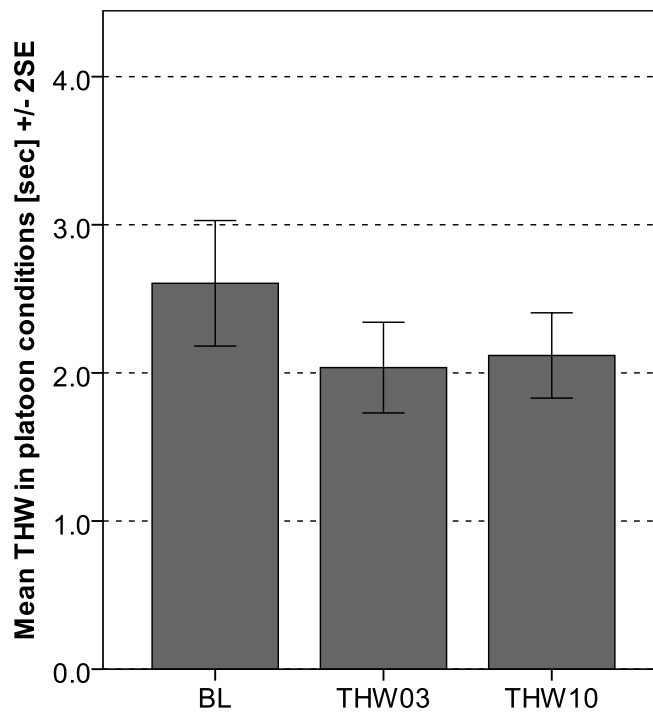


Figure 24 Averaged adopted mean THW and standard error (+/- 2SE) in the three traffic conditions (BL, THW03, THW10) (N = 42)

The mean adopted THW changed significantly across the drives [$F_{(1.72, 70.32)} = 18.97$, $p = .00$, $\eta_p^2 = .32$]. Planned contrasts revealed that traffic significantly increase THW as compared to a baseline drive with no traffic (BL vs platoons) [$F_{(1, 41)} = 26.48$, $p < .05$, $\eta_p^2 = .39$] but revealed no significant difference between the two platoon conditions (THW03 vs THW10) [$F_{(1, 41)} = 1.13$, $p = .29$, $\eta_p^2 = .03$].

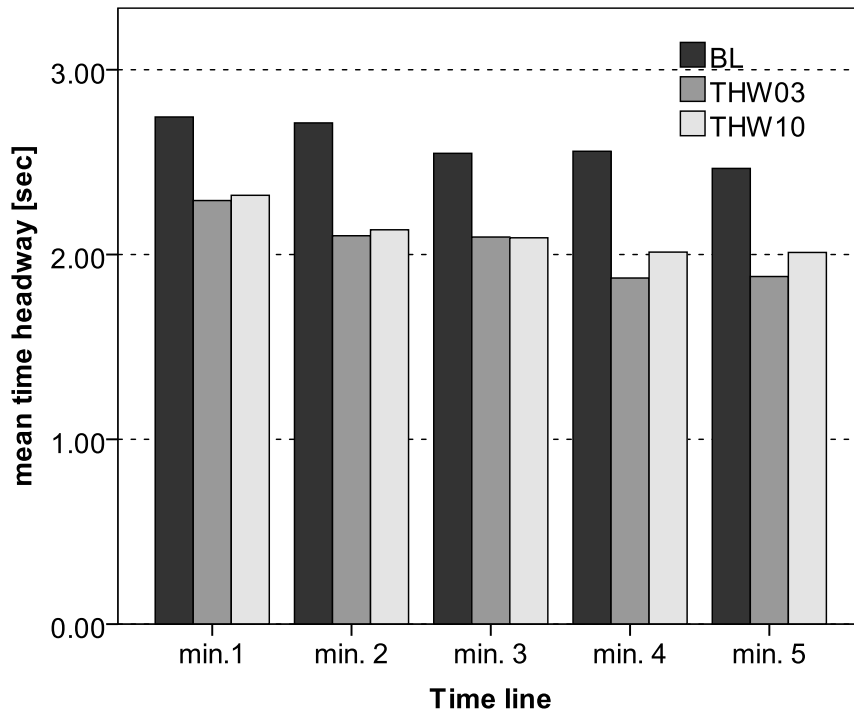


Figure 25 mean THW every minutes, 5 in total (N = 42)

As aforementioned, the time required for drivers to adapt their behaviour is an unknown variable. To get an insight into the changes in distance keeping throughout the drive, the mean THW was calculated for each minutes of the trial (five in total). Figure 25 shows firstly a general time-on-task effect as all the mean values decreased in the course of the trial and secondly, a gap between THW03 and THW10 becomes apparent in the two last minutes of the trial.

Repeated-measures ANOVA showed a significant effect of the driving conditions on THW [$F_{(1.61, 66.27)} = 19.78, p < .05$] and a significant effect of the time [$F_{(2.20, 90.17)} = 10.76, p < .05$]. There was a significant linear trend of the factor time [$F_{(1, 41)} = 18.20, p < .05$] and planned contrasts revealed that a driving condition with no traffic was responsible for a higher THW compared to driving condition next to platoons of vehicles (BL vs platoon) [$F_{(1, 41)} = 11.25, p < .05$]. However, planned contrast comparing the two platoon conditions (THW03 vs THW10) revealed no significance. There was a significant interaction between the planned contrast (BL vs platoon) and the linear contrast [$F_{(1, 41)} = 31.41, p < .05$].

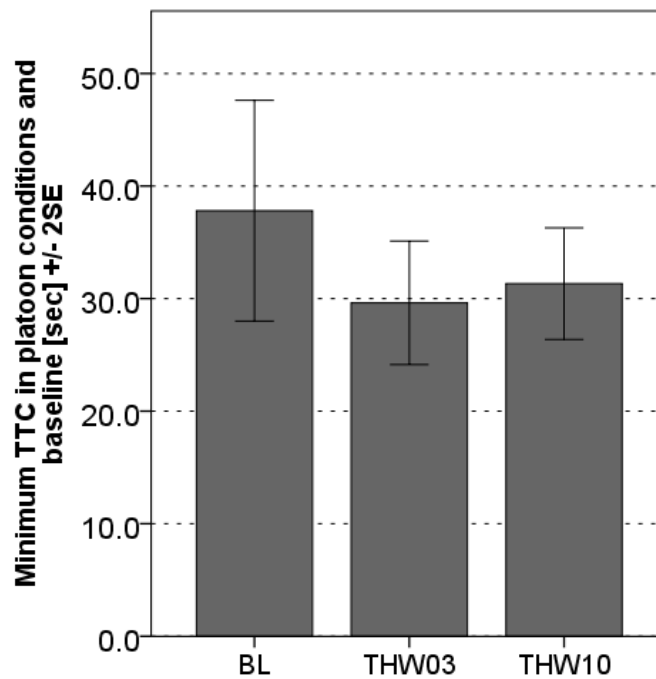
Time to collision (min)

Figure 26 Minimum TTC and standard error (+/- 2SE) in the three traffic conditions (BL, THW03, THW10) (N = 42)

Looking now at TTC will complete the picture of risks taken by the drivers. Figure 26 shows the minimum TTC, indicator for risk taken by drivers. Minimum TTC is higher in the Baseline ($M = 37.80$; $SD = 31.48$). There is an observable albeit smaller difference between the two platoon conditions: TTC is shorter in THW03 ($M = 29.62$; $SD = 17.62$) than in THW10 ($M = 31.33$; $SD = 15.92$). Results show that the main effect of TTC is marginally significant [$F_{(1.61, 66.08)} = 2.98$, $p = .07$, $\eta_p^2 = .50$].

Subjective data

After completing each scenario, drivers rated the perceived workload on the six NASA Task Load Index (NASA-TLX) scales (Hart & Staveland, 1988). Results are reported in Figure 27: the value 0 stands for the minimal amount of workload and 100 is the maximum. There is a significant factor effect [$F_{(1.73, 69.0)} = 4.69$, $p = .012$, $\eta_p^2 = .10$] and post-hoc pairwise comparisons show a significant difference between Baseline and the two platoon conditions but not between the two platoon conditions.

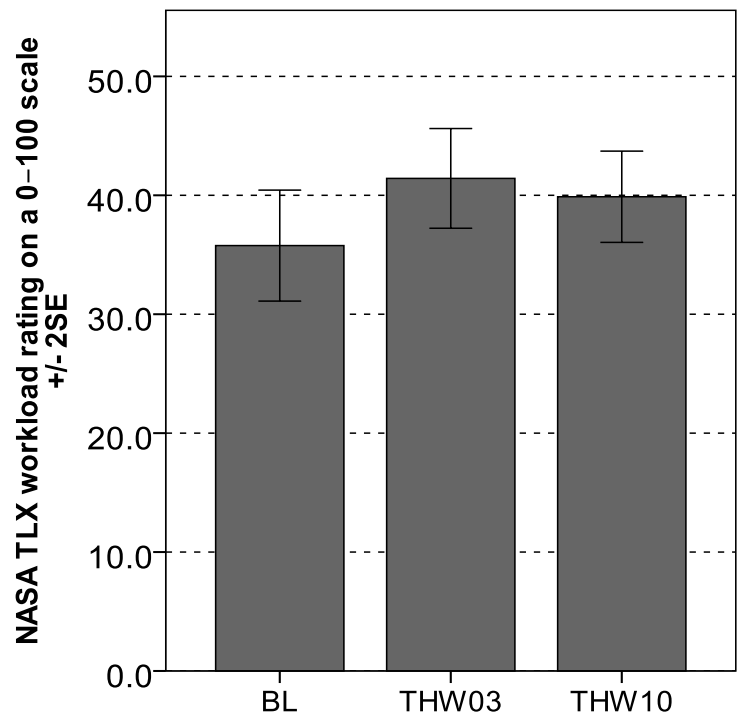


Figure 27 The effect of traffic condition (BL, THW03, THW10) on subjective workload as measured by NASA-TLX on a 0-100 scale (error bars represent +/- 2SE) (N = 42)

5.4.3 Personality and minimum adopted/preferred THW

Table 8 shows the Spearman’s rho correlation between personality characteristics, attributes and minimum preferred/ adopted THW. None of the personality attributes correlated significantly with the preferred THW. By contrast, some attributes were found to correlate significantly with the adopted THW. Anxiety was negatively correlated with the adopted THW in all traffic conditions (BL: $\rho = -0.39, p < .05$; THW: $\rho = -0.37, p < .05$; $\rho = -0.31, p < .05$), which means that ‘anxious’ participants tended to drive closer in the experimental study. The other significant correlation observed was that between the adopted THW and drivers’ Locus of Control (LoC): in THW03 ‘Internal’ participants tended to keep a larger THW than ‘External’ ones ($\rho = 0.34, p < .05$).

Table 8 Spearman's rho correlation between personality characteristics/ attributes and minimum preferred/ adopted THW (* Correlation is significant at the 0.05 level) (N = 42)

	Min. preferred THW			Min. adopted THW		
	BL	THW03	THW10	BL	THW03	THW10
Age	0.26	0.14	0.15	0.2	0.17	0.11
Gender	0.1	0.1	0.14	0.05	-0.05	0.11
Licence in year	0.21	0.11	0.14	0.2	0.22	0.13
Annual mileage	-0.02	0.01	-0.01	-0.15	-0.07	0.03
LoC	0.2	0.14	0.07	0.26	0.34*	0.27
Excitement	0.05	0	0.02	-0.05	0.05	-0.03
Anger	-0.06	0.01	-0.03	-0.24	-0.25	-0.16
Anxiety	-0.23	-0.11	-0.19	-0.39*	-0.37*	-0.31*
Altruism	0.27	0.24	0.18	0.17	0.22	0.13
normlessness	-0.18	-0.19	-0.12	-0.06	-0.08	-0.04
GEFT	0.18	0.21	0.19	-0.01	0.01	0.04
DBQ – E	-0.03	0.01	-0.04	-0.07	-0.01	-0.02
DBQ – HCV	-0.15	-0.15	-0.11	-0.18	-0.18	-0.19
DBQ – AV	-0.26	-0.18	-0.2	-0.07	-0.07	-0.09

5.5 Discussion

The main goal of the study was to investigate whether platoons with short THWs influenced drivers' THW. In addition, the following question was addressed here: are drivers ready to keep a THW that is shorter than the one they would prefer, just to conform to the new norm established by platoons? In a driving simulator study, participants were asked to follow a lead vehicle (LV) in three different traffic conditions. In two conditions, there was a platoon of vehicles in the inside

lane, where the THW between the vehicles was either large (THW = 1.0 s) or short (THW = 0.3 s). In a third baseline drive, the LV was the only vehicle present. Preferred THW was assessed after each traffic conditions with the psychophysical method of limits. Comparing the THW adopted in the simulated drives and preferred THW measured by means of the psychophysical method of limits informs about whether drivers would adopt a THW beyond their preferred one as a result of the influence of platoons.

Results showed a main effect of the drives on mean THW, a significant difference between the baseline and platoon conditions but no significant difference between the two platoon conditions. Hypothesis (1a) that drivers keep shorter distances (mean THW) in THW03 than in THW10 could not be verified.

A 2×3 factorial ANOVA showed a significant difference between the baseline and platoon condition and a significant difference between the two platoon conditions in terms of minimum THW, verifying hypothesis 1b. Results also showed a significant difference between the two THW types measured (minimum adopted and preferred THW). According to the latest result, the present study succeeded in disentangling two construct that were confounded thus far: minimum adopted and minimum preferred THW (hypothesis 2).

Comparing the two parameters gives evidence for a potential risk taken when a reduction of adopted THW occurs. In none of the conditions, drivers were going below their preferred THW. The results are not supporting the influence of social mechanisms in the behavioural adaptation of UVDs to short THWs. However, in platoon conditions and especially in THW03 drivers were very close in average to the limit of preferred THW. It can be concluded that in this experimental study, platoons with short THWs lead drivers to drive closer to their limits.

The present work introduced a promising method to investigate whether drivers are ready to conform to the norm in terms of THW established by platoons with short THWs. However, a limitation of the study is that it is still not clear what would have been the consequences (e.g. in terms of safety, workload, performance) of drivers keeping THWs below the minimum preferred THW. Further experimental studies need to clarify this point.

The major issue in the analysis of the impact of platoons on other drivers is that it is unclear which conditions are favourable for a distance adaptation to occur and several factors could have been manipulated such as: the behaviour of the LV, the exposure time, the frequency of exposure (short-, medium- and long-term effect), the conspicuity of platoon vehicles, the length of platoon vehicles, the penetration rate, the aim of the drive. Thus, further research work is needed to investigate the impact of these variables on non-platoon drivers. To investigate the origin of individual differences in the selection of both preferred and adopted THW, correlations between the two THWs and personality attributes were computed. It was found that none of the personality characteristics significantly correlated with the preferred THW. Contrarily, some of the personality characteristics showed a significant correlation with the adopted THW in some conditions. In terms of locus of control (LoC), 'Externals' tended to drive closer to the lead vehicle than 'Internals' in THW03. The correlation can be interpreted as an influence of the short THWs maintained in platoons. This effect is stronger on 'External' drivers. This finding is in line with the fact that 'Externals' were reported by several researchers for lack in caution in their driving style (Özkan & Lajunen, 2005). Further, Anxiety was found to be significantly correlated with adopted THW. It was thought that anxious participants would tend to keep a larger distance to the lead vehicle to avoid accidents (Ulleberg & Rundmo, 2003). Contrary to expectations, however, the correlation is positive indicating that anxious participants drove closer throughout all the drive. The results can perhaps be interpreted as an effect of the instruction: anxious participants feared losing track of the LV (that they had been instructed was guiding them to their destination).

Personality characteristics and attributes were not found to be determinants of preferred THW and only very few of them seem to be associated with the THW adopted by drivers depending on situational factors. In line with the idea raised in the introduction, it is argued here that preferred THW represents a range of THWs that drivers feel safe and comfortable with, depending on their perceived braking skills. Further, depending on the current situational factors, drivers will decide about a THW they wish to keep (adopted THW). As the results show, it is suspected that the influence of personality factors varies depending on situational factors. The processes described here are

depicted in a simple model (Figure 28). However, further research would be needed to develop and validate this model.

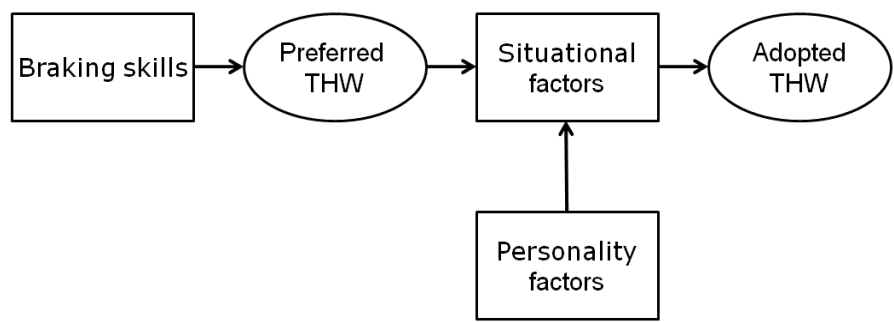


Figure 28 Relationship between preferred THW and adopted THW

5.6 Conclusions

One challenge in developing conclusions from the present study is that investigating the influence of other’s THW on a driver is a novel area of research and so it has not been possible to build on previous knowledge. The major issue is that it is unclear which conditions are favourable for a distance adaptation to occur and several factors could have been manipulated such as: the behaviour of the LV, the exposure time, the frequency of exposure (short-, medium- and long-term effect), the conspicuity of platoon vehicles, the length of platoon vehicles, the penetration rate, the aim of the drive. These factors were maintained constant but in light of the obtained results, parameters were isolated that could lead to significant results in a future trial. Certainly one of the most critical points is that the acceleration of the LV at the beginning of the simulated scenario was too high for some participants, who were consequently less likely to catch up with the LV. This problem is aggravated by the fact that the LV was driving at around 70 mph (UK’s speed limit on the motorway), forcing participants to exceed the speed limit to catch up. However, awareness about the violation was enforced by the presence of speed camera signs on roadside infrastructure (Figure 29).



Figure 29 Presence of speed camera signs on roadside infrastructure

Additionally, the assumption was made in the experimental trial of a carryover effect from one condition to the other. Precisely, once participants have made their idea of a THW, they might keep it through the trial. The presence of a carryover effect of THW from one condition to the other could explain the lack of significant differences between the two platoon conditions. The carryover effect of speed kept on highways on the connecting road are well known phenomenon (Casey & Lund, 1992). A similar effect could be observed concerning the distance.

Some other modifications could increase the impact of distances between platoons. Cars were used in the platoon to facilitate any social processes: it was assumed that drivers are keener to reproduce behaviour from other drivers that are similar to themselves. Based on the SEEV model (Wickens et al., 2001) (section 2.3.7), the allocation of visual attention to a certain visual channel is guided by the influence of four factors: the *salience* of the signal, the *effort* needed to move attention from previously fixated location, the *expectancy* of the signal, the objective *value* of processing information. In the context of this study, the visual channel occupied by platoons presented no value to drivers and the expectancy of something to happen in this channel was certainly very low as cars stayed in the same lane and kept the same speed and distance. Finally, none of the cars was outstanding because of the colour or the shape of the car so there was no particular salience in this channel either. As the visual channel is on the periphery of drivers' field of view, allocating attention to the channel causes some effort. As a result, the visual channel with the platoon was affected by an inhibitory force instead of positive ones, leading to a small probability of being attended. The

lack of evidence for a behavioural adaptation to the short THWs kept in platoons can be attributed to an insignificant distribution of drivers' attention toward this channel. Drivers' perception of platoons is a condition for behavioural adaptation to occur. Therefore, the probability of drivers allocating their attention to platoons has to be increased. Increasing the salience of vehicles in platoons was thought to add a positive force to the channel with the platoons, increasing the probability of drivers to allocate attention to this area. Trucks are more salient than cars because of their outstanding shape. Therefore, the following study will employ trucks instead of cars to increase saliency in the visual channel with platoons, increasing the probability of drivers in the vicinity to allocate their attention to this channel and to potentially be influenced by platoons.

Furthermore, distances between vehicles might be more perceivable to non-platoon drivers if they pass platoons rather than driving next to it at a similar velocity. Finally, the low-level simulator used for the purpose of the present study only offered a front vision. Using a medium-level simulator with side-views will certainly increase the visibility of the THWs within platoons.

Polynomial contrast revealed that THW decreased over time and planned contrast revealed a significant difference between THW adopted in the baseline and the two platoon conditions and there was a significant interaction effect between the two contrasts. A longer exposure to platoons could therefore lead to an increased difference in THW even between the two platoon conditions.

Keeping these critical points in mind, a new study will be carried out.

6 THIRD EXPERIMENTAL STUDY: THE EFFECT OF SHORT TIME HEADWAYS

6.1 Introduction

The hypotheses related to drivers' behavioural adaptation to short THWs kept in platoons were only partially verified in the second experimental study. Thus far, in the conditions tested, it cannot be concluded that THW adaptation of non-platoon drivers occurs when a platoon maintains short THWs in their vicinity. However, it is still possible that behavioural adaptation might occur when certain conditions are met.

Numerous factors of a given driving situation relating to the environment, vehicle and individual driver characteristics can have an effect on drivers' behaviour. However, the complexity of the driving task can make it difficult to isolate factors in order to study their effect on behaviour. Nevertheless, in the preparation for the present study, an attempt has been made to isolate factors that could have mitigated behavioural adaptation of drivers in the second experimental study and that could have been responsible for the lack of significance in driving parameters.

The experimental design of this third study was based on the second study, but was slightly modified to emphasise variables that have been identified through as being potentially "favourable" for the occurrence of behavioural adaptation or to control interfering variables that could have impeded behavioural adaptation. In the modified context, the nature of the task remained the same: participants were asked to follow a lead vehicle and changes in their driving behaviour were assessed with a particular focus on car-following behaviour. In addition, participants were continually confronted with platoons of vehicles in two conditions: in one condition the THWs were very short and in the other THWs were larger. However, in the present study the length of the driving task was increased as the effect showed a tendency to increase with time in the second experimental study.

It was noticed in the previous study that the high acceleration of the lead vehicle (LV) could have impeded participants catching-up with it. This effect may also have been reinforced by the presence of speed camera signs on roadside infrastructure. In the third study, the acceleration of the LV was therefore changed (1 m/s² instead of 3 m/s²) and the speed camera signs were removed.

Furthermore, a carryover effect of THW from one condition to the other was expected. To verify any carryover effect on THW kept by drivers in the study, the order of confrontation to platoon conditions (THW03 and THW14) was added as a variable. Hence, participants that were first confronted by platoons of vehicles at long THWs and were expected to keep generally a larger THW in the condition with short THW than those participants who first started with this condition. In chapter 5, parameters have been isolated that could increase the visibility of THWs within platoons and therefore favour their influence on the non-platoon driver nearby: the type of vehicles in platoon (trucks instead of cars), using a mid-level simulator with side-views and the speed difference between platoon and lead vehicles (3 kph instead of 0 kph) so that drivers passed a platoon instead of driving permanently next to it. To avoid having an unrealistically long platoon, the deployment of medium-sized platoons is required. Finally, a medium-level simulator with a wider forward field of view was employed to increase the visibility of the THWs within platoons.

6.2 Hypotheses

The experimental study is based on the assumption that behavioural adaptation observed on the platoon driver might also be observable on the non-platoon driver in the vicinity of a platoon.

Consequently, the aim of the present study was to verify hypothesis 1 already formulated in the previous experimental studies; that short THWs kept in platoons of autonomous vehicles influence the THW of non-platoon drivers in the vicinity.

- Hypothesis 1: There is an influence of the presence of platoons maintaining short THWs on drivers' car following behaviour. Non-platoon drivers adapt their behaviour to the short THWs maintained in a platoon by reducing significantly their:
 - a) mean adopted THW,
 - b) Minimum adopted THW.

If the hypothesis 1 is verified that participants generally keep a shorter THW in THW03 and because the influence of the lead vehicle increases with a decreasing distance to the lead vehicle (Vogel, 2002), smaller THW requires a faster braking response. Keeping a shorter THW supposed-

ly intensify alertness to anticipate any change in the LV's behaviour. A relationship between an increase in effort and alertness and a reduction in drivers' standard deviation of the lateral position (SDLP) has been found in the literature. In dual task performances, SDLP decreased in comparison to a single task performance (Brookhuis et al., 1991), whereas in this condition an increase would be expected as an effect of distraction. It has been interpreted that in dual task performance, an increase in task demand has led to mobilisation of effort and increased alertness resulting in improved performance (Hancock & Desmond, 2000). In a similar way, a reduction in THW in condition THW03 could lead to an increase in effort and alertness to anticipate any changes in LV's behaviour. Hence, drivers may display lower SDLP in that condition.

- Hypothesis 2: participants confronted with platoons keeping short THWs will show a lower SDLP than when confronted with platoons keeping large THWs.

As aforementioned, a factor was added in the second experimental study to find out if there is a carryover effect of one condition to the other.

- Hypothesis 3: participants first confronted by platoons keeping short THWs will generally keep shorter THWs to those platoons than participants that were first confronted by platoons keeping large THWs.

6.3 Method

6.3.1 Participants

A total of 30 participants were recruited for this study, all of whom had previous experience with TRL's driving simulator. The group consisted of 15 males and 15 females. Participants all held a valid driver's license for at least one year ($M = 20.93$ years, $SD = 13.88$ years). The age of the participants ranged between 20 and 63 ($M = 40.53$ years, $SD = 14.06$ years). The mileage ranged between 2000 and 56000 miles a year ($M = 11965.52$ miles, $SD = 9753.14$ miles). Participants were compensated for their time and expenses incurred by taking part in the study. None of the participants had taken part in any previous study on the effect of short THWs within automated vehicles platoons on other drivers.

6.3.2 *Material*

The experiment was performed using TRL's medium-fidelity driving simulator (please refer to Chapter 4, section 4.3.2, for a detailed description of the simulator).

6.3.3 *Experimental design and procedure*

Before the trial, participants completed a demographic questionnaire (APPENDIX C) and were also asked to sign two exemplars of a consent form (APPENDIX A). Participants were given written instructions about the experiment at the beginning (see APPENDIX E). These asked them to follow a lead vehicle on a UK three-lane highway and specifically to stay in the same lane and not to lose track of the lead vehicle. As in experiment 1, messages appeared on the screen when participants were either too far behind the lead vehicle or if they moved out of the designated lane.

The inside lane (left lane as driven in the UK) was dedicated to the platoons. There were four platoons in total and each platoon was driving at a constant velocity (90 kph = 55.92 mph). This was just below the constant velocity maintained by the LV (93 kph = 57.79 mph). The constant speed of the lead vehicle means that variations in THW can exclusively be attributed to the participants' behaviour. Since the driven vehicle was required to follow the lead vehicle, participants drove in the middle lane adjacent to the platoons (when present). At the beginning of the study, the lead vehicle accelerated slowly (1 m/s) so that participants could easily catch up and start the car-following task. The outside lane was occupied by occasional fast-moving traffic (140 kph = 87 mph).

The experimental design involved two factors: the THW adopted in platoons and the treatment order. The first factor had two levels: in one condition (THW03) the THW adopted in platoons was 0.3 s; and in the other (THW14) the THW was 1.4 s. In comparison to the second experimental study, the distance between vehicles was increased in the condition with larger THW in platoons. This was accomplished by the deployment of different medium-sized platoons instead of a single long platoon.

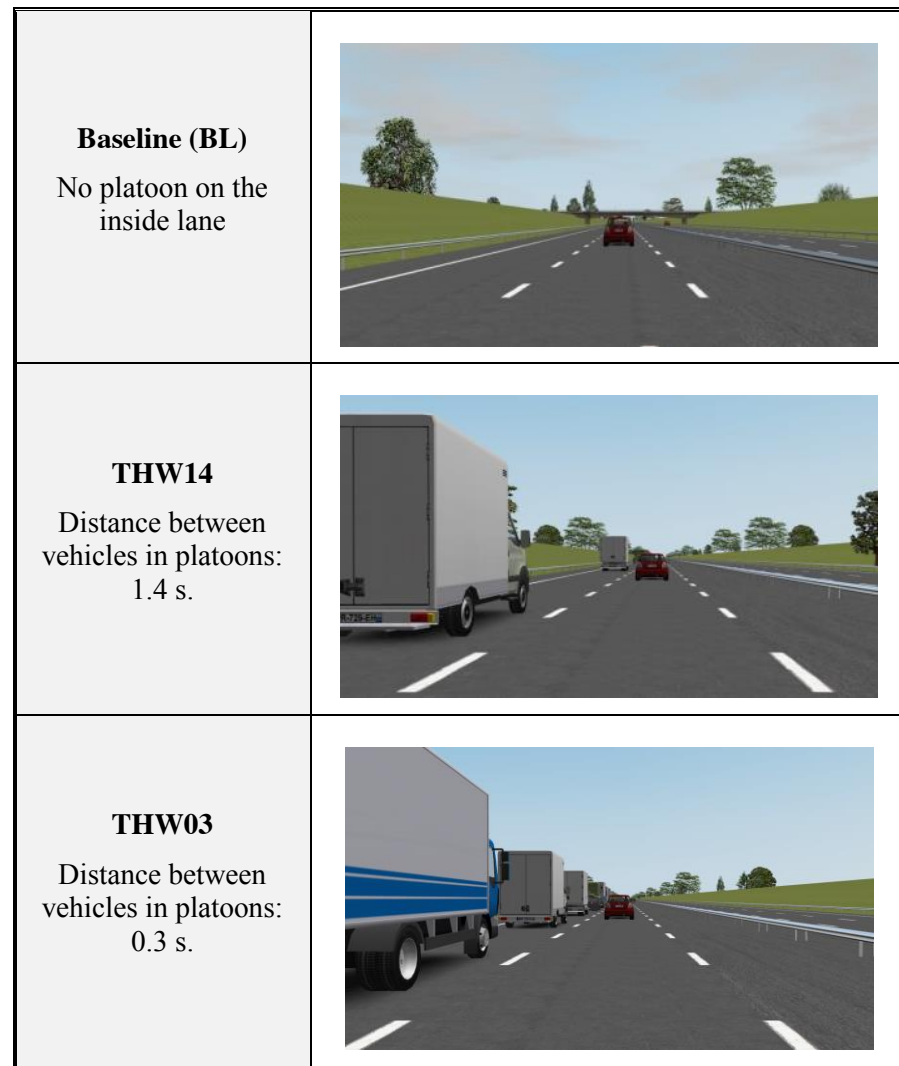


Figure 30 Screenshots from the simulated three-lane motorway with platoons in the inside lane, LV in the middle lane in THW14 and THW03 and no platoons in BL.

It was intended to have platoons of equal size in both platoon conditions so that ideally the total time spent next to each platoon can be constant throughout each condition. However, changing the distance between vehicles in a platoon automatically changes its size. Keeping a similar size between platoons despite different THWs is possible if either the size of vehicles or their number is adjusted. The second option (adjusting the number of vehicles) was selected as it could be easily implemented in the simulator. Hence, the number of vehicles in a platoon (10 trucks in THW03 and 4 trucks in THW14) and the distance between the vehicles were manipulated. The total length of platoon was similar between THW03 (= 128.147 m) and THW14 (= 129.181 m) albeit slightly smaller in THW03 compared to THW14 but this difference was less than the Weber ‘just noticeable difference’ fraction for line length (Coren et al., 1994) and so was unlikely to be detected by

participants. The first vehicle of each platoon held a THW of 2.2 s. with the last vehicle of the platoon in front, which represents a distance of 55 metres at 90 kph. Figure 30 shows a visual representation of the driving scene in the three conditions from the perspective of the ‘ego’ vehicle.

Table 9 Study design of the third experimental study

	1 st Drive	2 nd Drive	3 rd Drive
Group Small-Large	Baseline	THW 03	THW 14
Group Large-Small		THW 14	THW 03
	16 minutes	16 minutes	16 minutes

The second factor was determined by the treatment order, as a carryover effect from one condition to the other was suspected. Participants were randomly assigned to one of the groups following a counterbalancing plan. Before starting the treatment conditions, participants were asked to complete a baseline (BL) drive in which there was no platoon in the left lane (see Table 9). The aim of the baseline was to assess drivers’ THW before they underwent the treatment. Hence, comparing driving parameters obtained in the two groups enabled a determination of how similar both groups were in terms of car-following behaviour in looking at the driving behaviour parameters. To counterbalance the BL with the treatment would have excluded any learning effect or effect of the time but potential carryover effects would not have been avoided. Participants drove for 16 minutes in each condition. The first minute was not included in the data analysis because it was considered as the lead-in to the study. The procedure is illustrated in Figure 31.

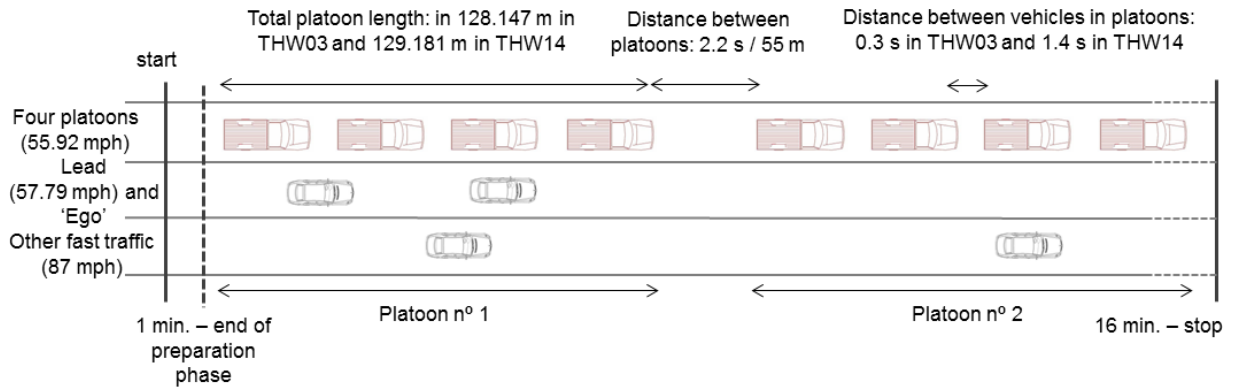


Figure 31 Schema of the study design

6.3.4 Measures

Driving and environment parameters were synchronously collected at a frequency of 20 Hz. The following parameters were collected to address the study hypotheses: THW (mean, min. and max.), TTC (min.) and Lateral Position (LP). THW is calculated as follows: distance to the next vehicle [m] / speed [m/s], the distance to the next vehicle is measured along the road from the front of the “ego” vehicle to the rear of the lead vehicle. Mean THW was calculated as a mean value for each participant. LP is defined as the difference in metres between the centre of the participant’s car and the middle of the driving lane. LP was used to calculate the standard deviation of LP (SDLP).

6.3.5 Analysis

Data obtained from the Baseline were considered separately from those for the platoon conditions as the baseline was treated as a control condition to verify that the two groups were comparable using an independent t-test. The analysis of the data in platoon conditions was conducted with a 2×2 mixed ANOVA (within subject variable: platoon conditions, between subject variable: groups). In cases with more than two repeated measures, the assumption of normal distribution was verified with a Shapiro-Wilk test before conducting ANOVA tests. Greenhouse-Geisser (1959) correction was applied if the assumption of sphericity was violated. Variance homogeneity was verified with the Levene test. Furthermore, pairwise comparisons were computed and p -values were corrected according to the Bonferroni method.

The end of the data was missing for participant n° 2 in condition THW14 because a vehicle in the traffic unexpectedly pulled-in between the ‘ego’ and LV. The beginning of the data for participant n°8 was missing in BL because the participant was too far behind the LV.

6.4 Results

6.4.1 Following tactic

The difference in mean THW between Small-Large and Large-Small in the Baseline was 0.08 s (Small-Large: $M = 3.31$, $SD = 1.35$; Large-Small: $M = 3.39$, $SD = 1.29$) (Figure 32) and this difference between the two groups was not significant [$t_{(28)} = -.19$, $p = .85$]. Thus, the two groups were considered as equal and comparable in respect to car-following behaviour.

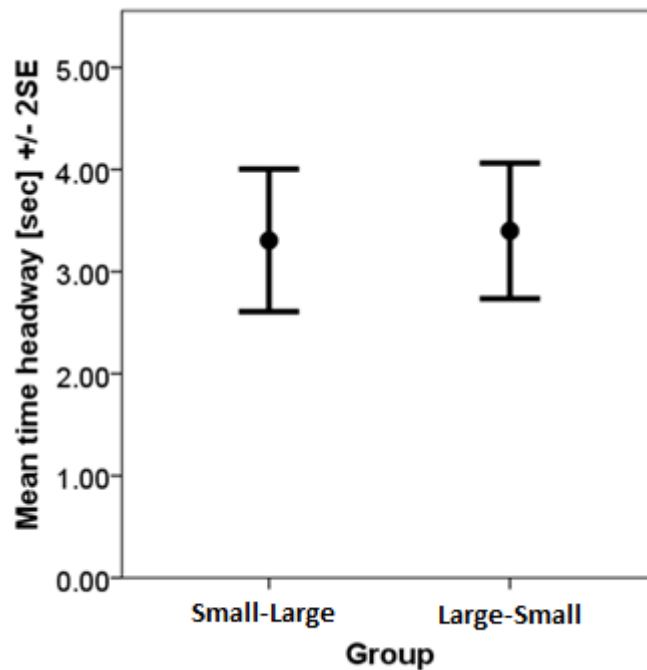


Figure 32 mean THW [s] in Baseline for each group (Group Small-Large started with THW03 first and Large-Small with THW14) and standard error (+/- 2SE) (N = 30)

With regard to the mean THW, the ANOVA showed a significant main effect of platoon condition on the average THW [$F_{(1, 28)} = 4.74$, $p = .04$, $\eta_p^2 = .14$]. Participants maintained on average a smaller THW in condition THW03 ($M = 1.87$, $SD = .18$) than THW14 ($M = 1.99$, $SD = .17$). There is a

difference of 0.12 s between the two conditions. At a speed of 93 kph (57.79 mph) this represents a distance of 3.1 meters.

Furthermore, a carryover effect was expected: Small-Large was expected to show a smaller THW in condition THW03 than Large-Small and a smaller THW in THW14 as well. However, results showed no significant effect of group [$F_{(1, 28)} = .80, p = .38, \eta_p^2 = .03$]. Power calculation shows a low statistical power equal to .14. There was no significant interaction effect either [$F_{(1, 28)} = .88, p = .36, \eta_p^2 = .03$]. In Figure 33, the mean THW is displayed for the two groups and throughout the two platoon conditions.

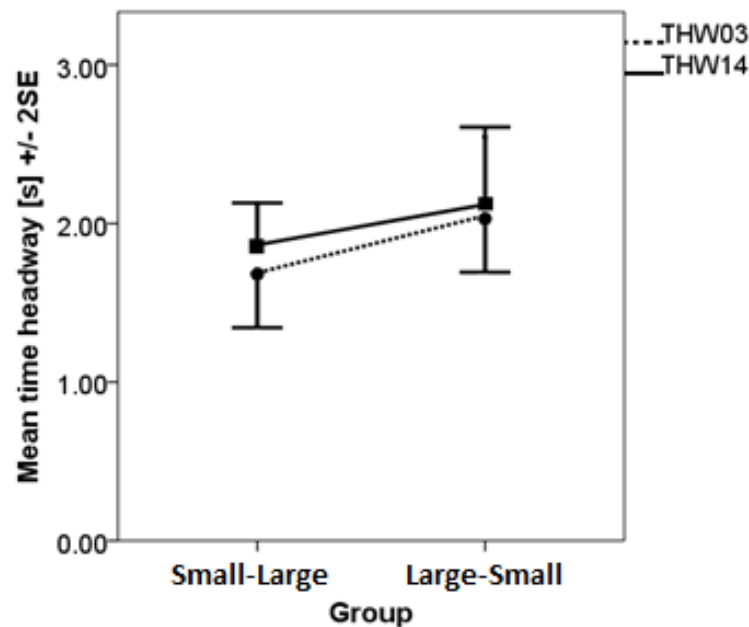


Figure 33 mean THW [s] in platoon conditions (THW03 and THW14) for each group (Small-Large started with THW03 first and Large-Small with THW14) and standard error (+/- 2SE) (N = 30)

Further analysis of mean THW examined how drivers' THW changed depending on whether there was a platoon adjacent to them or a gap between two platoons. The aim of this analysis was to find out about the strength of the effect and especially to see if the effect immediately disappeared as soon as drivers passed the platoon or if it persisted afterwards.

A simulated 'laser' placed on the 'ego' vehicle's left side (beam opening: 50°; beam range: 50 metres) enabled detection of vehicles situated to the left of the 'ego' vehicle within this region. It was therefore possible to determine when participants were driving next to a platoon and when they

passed it. The length of the study was based on time (and not on distance) and stopped after 16 minutes regardless of the participants' position. As there was a high variability between the THW maintained between participants, the amount of time spent next to the last (4th) platoon varied. Those participants maintaining a high THW were only at the beginning of the 4th platoon when the scenario stopped. A $4 \times 2 \times 2$ mixed ANOVA was conducted to test the similarity in the amount of data for the periods next to a platoon and employed the two following within variables: 1) the platoon number (1 to 4 with platoon n°1 being the first platoon encountered by participants and platoon n°4 respectively the last one) and 2) the platoon condition (THW03 vs. THW14) and the between factor was the groups Small-Large and Large-Small. There was a significant difference of the amount of data in the factor platoon number [$F_{(2.06, 53.48)} = 11.32, p < .05, \eta_p^2 = .30$]. Pairwise comparison with Bonferroni correction shows a significant difference in the amount of data only between platoon 4 and the other platoons 1, 2 and 3. Between the platoon 1, 2 and 3 there was no significant difference. Consequently, data relating to the 4th platoon was excluded from the analysis and only platoon 1, 2 and 3 were considered for the period next to a platoon and used to calculate an average THW for the period spent next to a platoon.

Participants spent the same amount of time next to each platoon but the amount of time spent next to platoons is larger than the amount of time spent between two platoons. The reason is simply that the length of platoons is higher than the separation length between two platoons. The platoon length is respectively 128.147 m for THW03 and 129.181 m for THW14. The separation length between two platoons is 55 m. Because there is a difference in platoon length and separation length between two platoons, there is a difference in the amount of time spent either next to a platoon or between two platoons. The implication of this difference is that the effect of being between two platoons loses power in comparison with the effect of being next to a platoon as the exposition time is longer.

A $2 \times 2 \times 2$ mixed ANOVA was conducted to test the influence of following factors on mean THW: the within subject factors were THWs in platoons (THW03 vs. THW14) and period (next to platoon 1, 2 and 3 vs. between platoons 1, 2, 3 and 4); the between subject factor was group (Small-Large vs. Large-Small). There was a significant effect of the factor platoon [$F_{(1, 28)} = 9.99, p$

$<.05$, $\eta_p^2 = .26$] and also a significant effect of the factor period [$F_{(1, 28)} = 5.43$, $p < .05$, $\eta_p^2 = .16$]. In addition, results show the following significant interaction effect: platoon \times period, $F_{(1, 28)} = 10.04$, $p < .05$, $\eta_p^2 = .26$. There was still no significant effect of the factor group, $F_{(1, 28)} = .89$, $p = .35$, $\eta_p^2 = .03$. The drivers kept a THW of 1.90 s on average ($SD = .18$) when driving next to the platoon and a THW of 2.03 s on average ($SD = .17$) when driving between the platoons. Therefore, even if the time spent between two platoons is shorter than the time spent next to a platoon, it is sufficient to significantly affect drivers' THW. In Figure 34, the mean THW is displayed for the two groups, throughout the two platoon conditions and the two different periods (next to platoon vs. between two platoons).

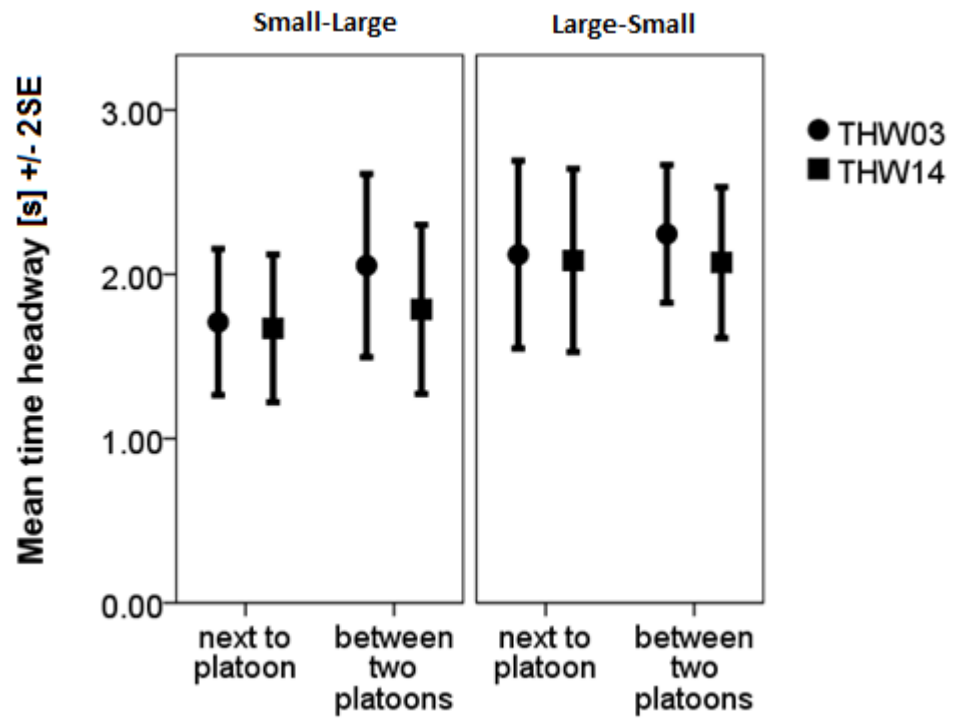


Figure 34 Mean THW [s] in condition THW03 and THW14 for groups Small-Large and Large-Small when driving next to a platoon or between two platoons (N = 30)

6.4.2 Following safety

Looking at the minimum THW enabled analysis of risks taken by the driver. In addition, maximum THW was analysed as an exploratory variable. There was no significant difference between the two groups in Baseline for minimum THW [$t_{(28)} = .33$, $p = .74$] and maximum THW [$t_{(28)} = -.23$, $p = .82$]. There was a significant main effect of platoon conditions on the minimum THW [$F_{(1, 28)} =$

4.60, $p < .05$, $\eta_p^2 = .14$] and on maximum THW [$F_{(1,28)} = 4.40$, $p < .05$, $\eta_p^2 = .14$]. However, there was no effect of group [min. THW: $F_{(1,28)} = 1.21$, $p = .28$, $\eta_p^2 = .04$; max. THW: $F_{(1,28)} < .05$, $p = .97$, $\eta_p^2 < .05$] and neither was there a significant interaction effect for both parameters [min. THW: $F_{(1,28)} = .09$, $p = .77$, $\eta_p^2 < .05$; max. THW: $F_{(1,28)} = .10$, $p = .76$, $\eta_p^2 < .05$]. As illustrated in Figure 35 a), the mean of minimum THWs was smaller in THW03 ($M = 1.00$, $SD = .10$) than in THW14 ($M = 1.16$, $SD = .13$) and Figure 35 b) illustrates that mean of maximum THWs was smaller in THW03 ($M = 3.45$, $SD = .29$) than in THW14 ($M = 3.87$, $SD = .28$).

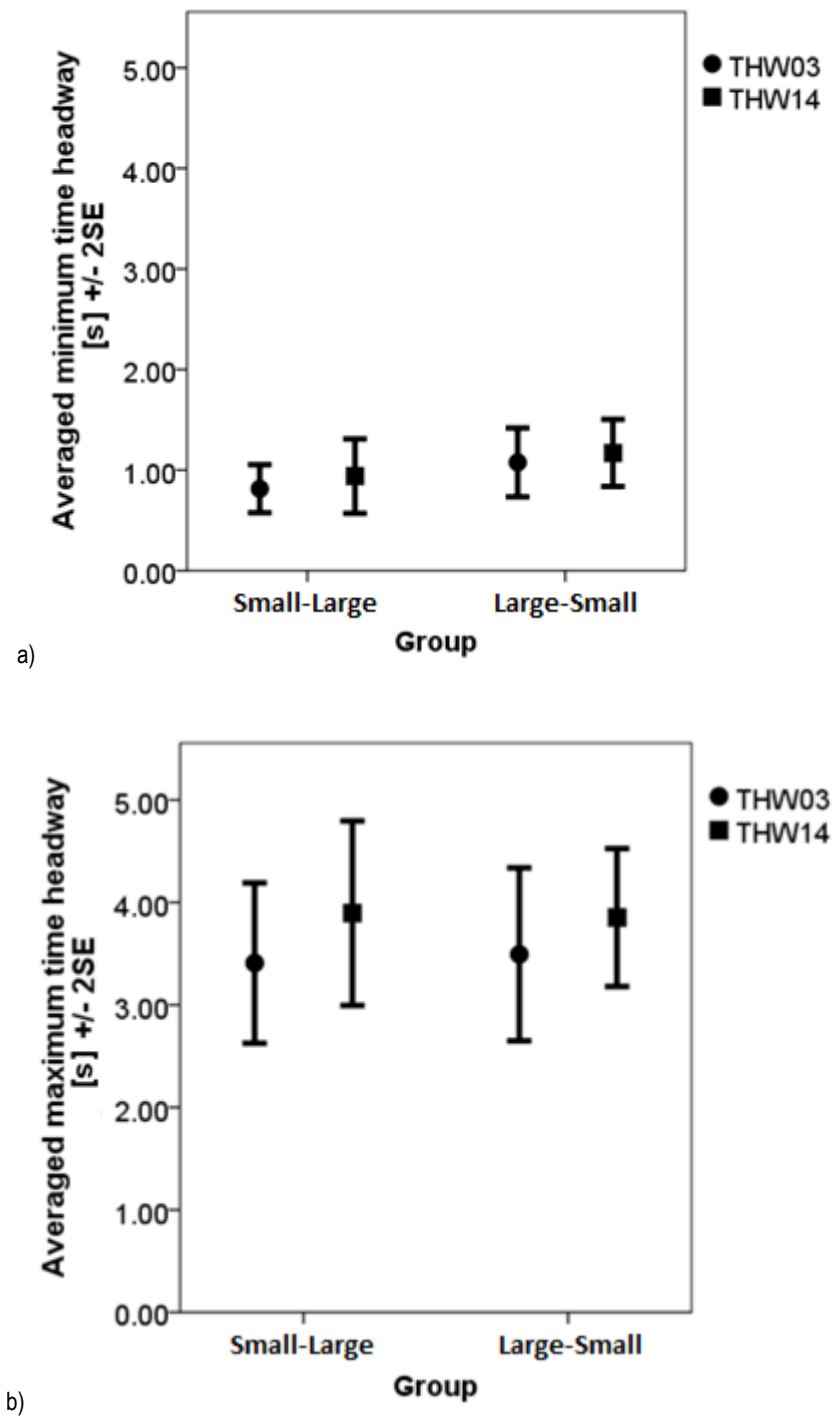


Figure 35 Averaged minimum (a) and maximum (b) THW [s] in platoon conditions (THW03 and THW14) for each group (Small-Large started with THW03 first and Large-Small with THW14) and standard error ($\pm 2SE$) ($N = 30$)

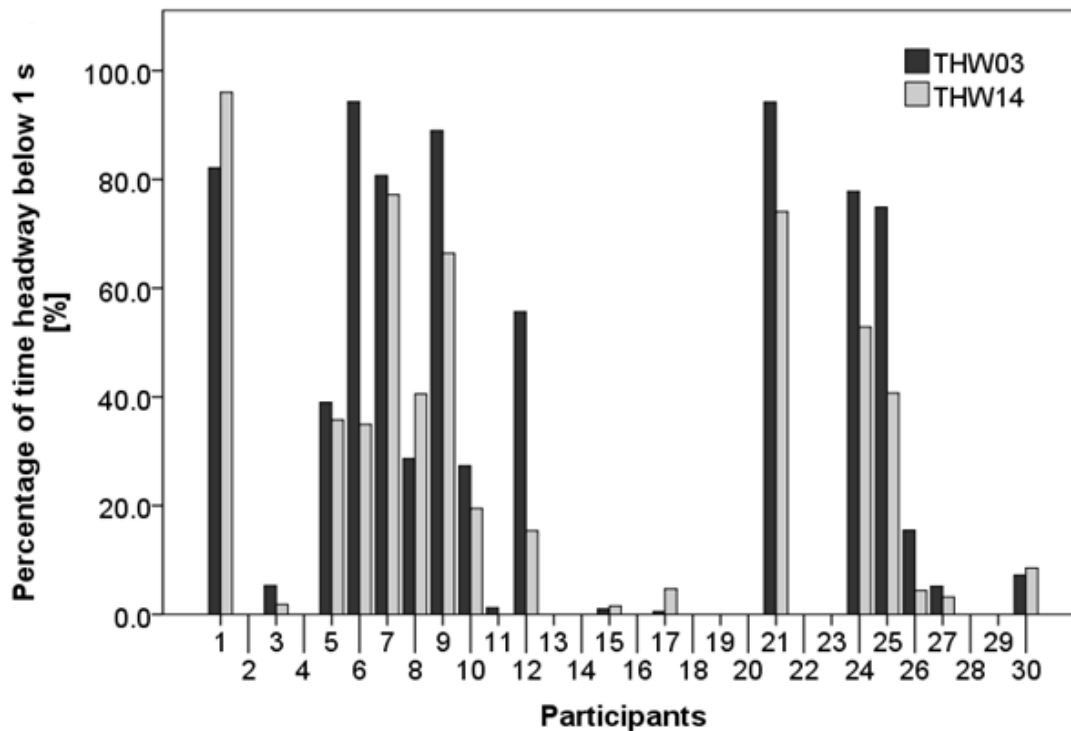


Figure 36 Percentage of time headway [%] under the critical threshold of 1 s in the two platoon conditions (THW 03 and THW14) (N = 30)

Running an ANOVA on the percentage of time spent under the critical threshold of 1 s required the within groups being normally distributed. However, as displayed in Figure 36 many participants permanently drove over a THW of 1 s and therefore showed the value 0 in terms of percentage spent below the threshold, which resulted in a skewed distribution. Shapiro-Wilk tests showed that the within groups differed significantly from a normal distribution. In addition, Levene's tests showed that there was no equality of variances. As these two assumptions have been violated, it was thought prudent not to conduct an ANOVA on the percentage of time spent under a THW of 1 s. However, a related samples t-test was calculated and only participants showing a value not equal to 0 in both conditions THW03 and THW14 were considered. Results of the related samples t-test showed a significant difference between the two platoon conditions; $t(16) = 2.50$, $p = .02$. On average, participants spent more time under the critical threshold of 1 s in THW03 ($M = 45.79$, $SD = 36.67$) than in THW14 ($M = 33.98$, $SD = 30.41$). Results are displayed Figure 37.

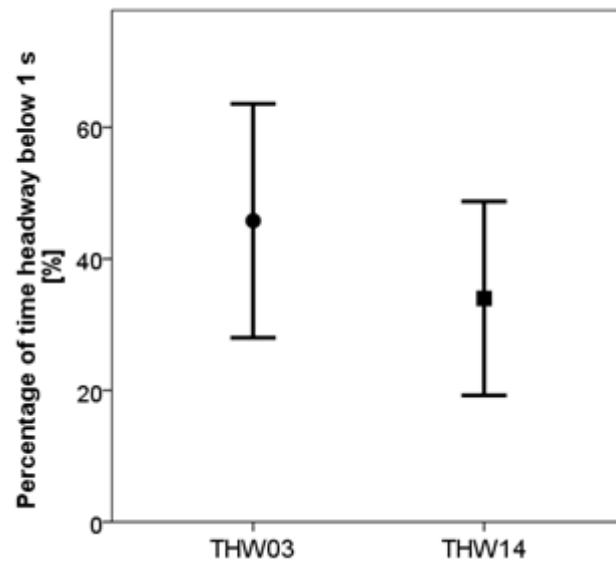


Figure 37 Percentage of time spent under the critical threshold of 1 s for participants showing a value not equal to 0 in the two conditions THW3 and THW14 (N = 17)

The last indicator of drivers' safety to be analysed but without relation to hypotheses, was minimum TTC. There was no significant difference between the two groups in the baseline, $t(28) = -.02$, $p = .98$. Results of the ANOVA showed no significant difference in the factor platoon [$F_{(1,27)} = .03$, $p = .87$, $n_p < .05$] and group [$F_{(1,27)} = 1.22$, $p = .28$, $n_p = .04$]. There was no significant interaction effect either [$F_{(1,27)} = .15$, $p = .70$, $n_p < .05$]. Results are displayed in Figure 38.

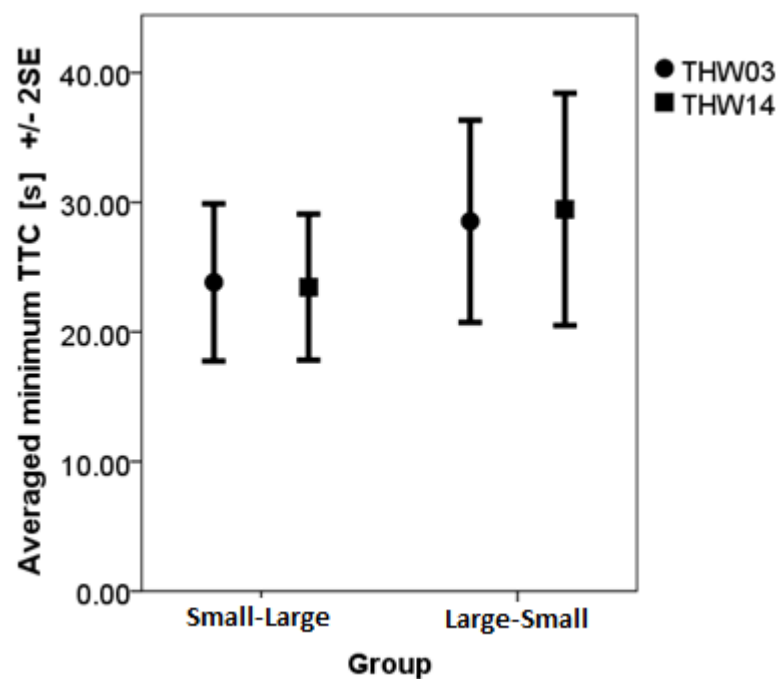


Figure 38 Averaged minimum TTC [s] in platoon conditions for each group (Small-Large started with THW03 first and Large-Small with THW14) and standard error ($\pm 2SE$) (N = 30)

6.4.3 Lateral deviation

With regard to the standard deviation of lateral position (SDLP), there was no significant difference in the parameter SDLP between the two groups in the baseline [$t(28) = .50, p = .62$]. However, results of a mixed ANOVA showed a significant difference between the two platoon conditions [$F_{(1, 28)} = 9.85, p < .05, n_p = .26$]. Interaction effect [$F_{(1, 28)} = .02, p = .90, n_p < .05$] and an effect of the factor group [$F_{(1, 28)} = .15, p = .70, n_p < .05$] were not present in the SDLP data. As observable on Figure 39, the SDLP was smaller in THW03 ($M = .17, SD = .01$) than THW14 ($M = .18, SD = .01$).

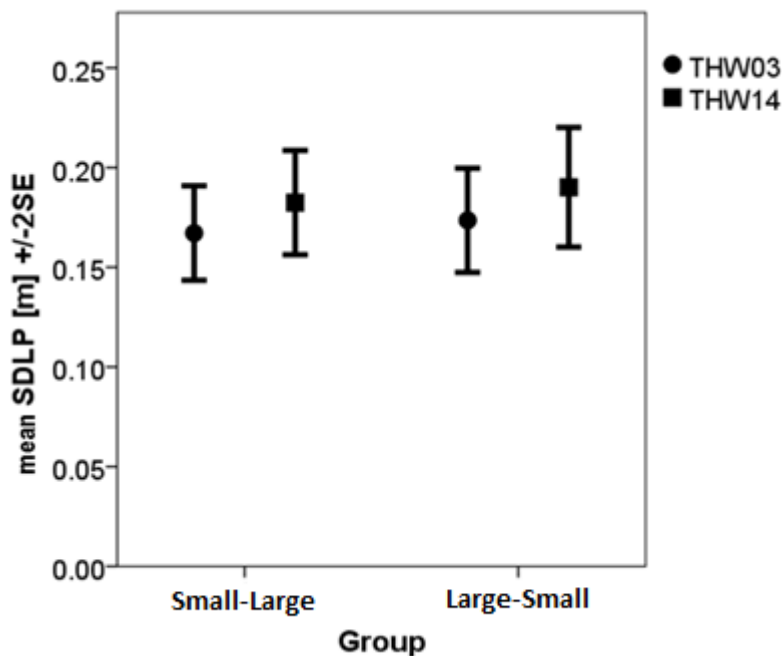


Figure 39 Mean SDLP in platoon conditions and baseline [m] +/- 2SE for each group (Small-Large started with THW03 first and Large-Small with THW14) (N = 30)

6.4.4 THW over time

If THW is plotted over time, an approximately sinusoidal function emerges. It is important to remember that, as the lead vehicle was constantly driving at the same speed, the fluctuation in THW can only be attributed to the following vehicle. Drivers did not maintain THW at a constant value but instead THW fluctuated around the mean value. Specifically, these diagrams reveal that drivers are slowly accelerating toward the LV until the distance is perceived as too close for the prevailing situation and they consequently release their foot from the accelerator and decelerate until the dis-

tance is perceived as too far leading drivers to resume acceleration. A microscopic model of car-following behaviour presented in the literature review (see chapter 2.4.2) that captures this fluctuation is the Action Point Model (Brackstone and McDonald, 1999; Brackstone and McDonald, 2007). Briefly, the core process of car-following as described by this model consists of alternating periods of closing and opening gaps to the lead vehicle. This fluctuation is induced by perceptual thresholds, on the basis of which drivers regulate the distance toward the lead vehicle in order to keep a position where no perceptual changes are noticed. The consideration of perceptual thresholds makes the Action Point Model one of the first microscopic models considering human parameters relevant for control of car-following. The visual thresholds are clearly visible on the diagram plotting relative speed and spacing, which results in a typical close following spiral as presented in the literature review (chapter 2.4.2). However, the Action Point Model was criticised for a lack of consideration of human factors that could explain the inter- and intra-variability in car-following behaviour (Boer, 1999).

It emerges from the data-sets that, in relation to the sinusoidal THW patterns, mean THW appears to be inversely correlated with its frequency and, in particular, directly correlated with its amplitude. Consequently, a first attempt to understand the underlying factors of the inter- and intra-individual differences consisted of calculating a correlation between mean THW and SD of THW. Beforehand, variables were tested relating to the assumption of normality by means of the Shapiro-Wilk test. As three variables were significantly deviating from a normal distribution, correlations were calculated with the non-parametric Kendall's tau rank correlation. Results always showed significant correlations and the correlation was moderate in the Baseline ($\tau = .37, p < .05$) and THW14 ($\tau = .46, p < .05$) and large in THW03 ($\tau = .61, p < .05$) (Figure 40). That is, drivers who adopt a close distance generally have a smaller *SD* of THW than drivers who prefer to follow at a larger distance.

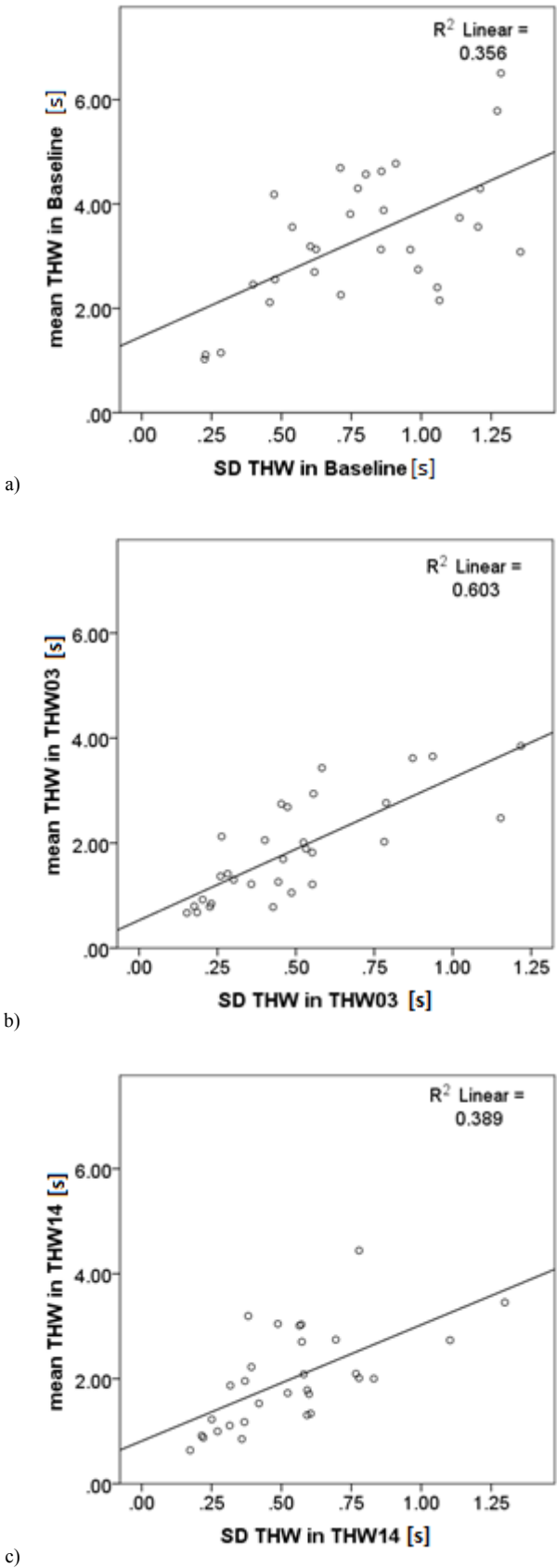


Figure 40 Scatter plot with line of best fit for mean THW and SD of THW in condition BL (a), THW03 (b), THW14 (c) (N = 30)

Furthermore, it emerges from looking at the graphs of THW over time for all participants, that drivers can be approximately classified into three groups: those who constantly keep a short THW and accordingly show small amplitudes and high frequencies (e.g. Figure 41, N6); those who always keep a large THW with accordingly high amplitudes and small frequencies (e.g. Figure 41, N3); and those who show a mix of processes, using generally large THWs in the baseline and reducing THWs in platoon conditions (e.g. Figure 41, N1).

However, as there is a linear relationship between mean THW and SD of THW, it is not possible to separate the high amplitudes and small frequencies from the small amplitudes and high frequencies by means of statistical tools. A qualitative model of driver car-following behaviour separating the two processes responsible for the two different kind of wave is likely to be helpful. Parameters of the two processes need then to be identified in a separate experimental procedure. This methodology has been implemented by Donges (1978) to differentiate two levels (open-loop and closed-loop control) in the lateral control of the vehicle.

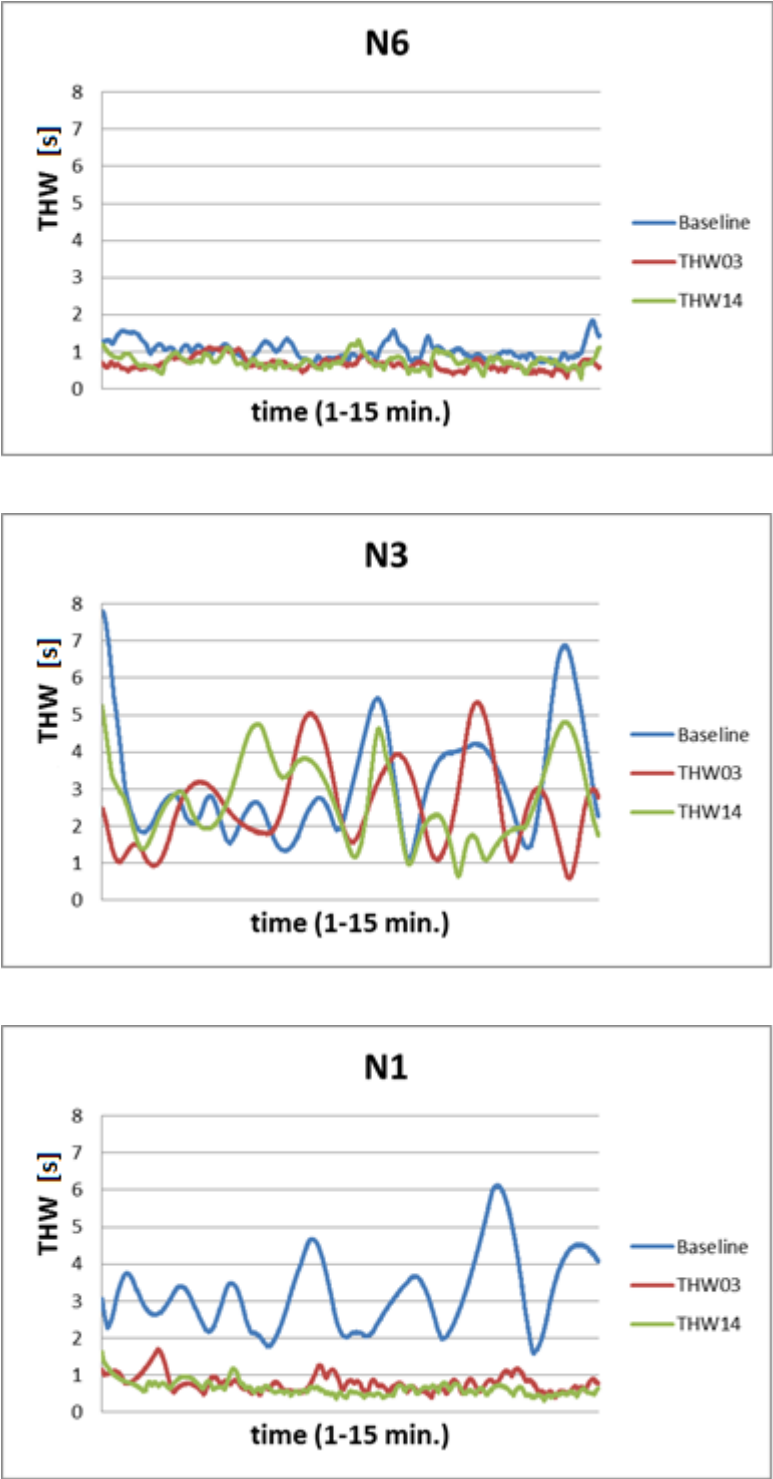


Figure 41 Difference between drivers in the frequencies, amplitudes and mean THW through the different conditions illustrated by means of three data-sets (N6, N3, N1).

6.5 Discussion

The main goal of the study was to examine the influence of the THW kept in platoons of vehicles on the driver nearby in terms of their chosen THW, with implications for safety and tactic relating to headway maintenance. In a medium-fidelity driving simulator study, participants were asked to follow a lead vehicle (LV) in three different traffic conditions. In two conditions there was a platoon of vehicles in the inside lane, where the THW between the vehicles was either large (THW = 1.4 s) or short (THW = 0.3 s). In a baseline drive, the LV was the only vehicle present. Primarily, the impact of THWs kept in platoons on drivers' tactic and safety was assessed by analysing a range of driving performance measures.

6.5.1 *Effect on following behaviour*

The analysis of the mean THW showed that there was a significant difference between the two platoon conditions. Therefore, results verified hypothesis 1(a) that the presence of platoons of trucks maintaining short THWs in traffic have an influence on drivers' mean THW. Results also showed that there is a significant difference in THW when comparing the period spent next to a platoon and the one between two platoons. It can thus be interpreted that the effect is not long-lasting and dissipates when drivers are no longer exposed to a platoon. This result is supported by the fact that no significant carryover effect from one condition to the other was found.

A limitation of the study is that the results cannot be generalised to car-following in general, as participants were told to stay in the same lane as the lead vehicle and not to lose track of it. The instruction thus created an atypical car-following situation.

Concerning the safety implications of THWs kept in platoons on surrounding traffic, drivers reduced their THW toward the lead vehicle as measured by minimum THW (hypothesis 1b was verified) but also maximum THW was significantly shorter in THW03 and a majority of participants spent more time under the critical threshold of 1 s. However, there were no significant differences in minimum TTC. that drivers tend to reduce their THW toward a LV when driving in the vicinity of a platoon keeping short THWs. A decrease in THW increases the probability of a collision. This

statement is supported by the fact that the shift in THW leads to drivers spending more time with the critical threshold of under 1 s. In contrast to the two previous studies, experimental study 3 showed significant results in the car following indicators mean, minimum and amount of time spent below 1 s, verifying hypothesis 1. The successive modifications to the experimental design made first to study 1 and then to study 2 lead to experimental study 3. Understanding the differences between experimental study 2 and 3 enables to better understand which factors were responsible for a behavioural adaptation to occur. The issue related to this is that many factors were changed between the two consecutive studies. Hence, it is unclear which factors are more responsible for behavioural adaptation to occur. The following factors were changed between the two studies and could therefore have had an implication on the occurrence of the effect:

- *The type of vehicles in platoons:* trucks were used in the platoon instead of cars to increase saliency in the visual channel with platoons, increasing the probability of non-platoon drivers' to allocate their attention to the channel and hence to be influenced by platoons.
- *The speed difference:* LV's speed was higher than vehicles' speed in the platoons enabling participants to pass platoons rather than driving next to it at a similar velocity. It was assumed that distances between vehicles might be more perceivable to non-platoon drivers if they pass platoons rather than driving next to it at a similar velocity.
- *The length of platoons:* as a consequence of the change in speed difference, different medium-sized platoons were deployed instead of a single long platoon.
- *The arrangement of vehicles in platoon:* It was intended to have platoons of equal size in both platoon conditions (large THW vs short THW) to get a constant time spent next to each platoon throughout each condition. To get platoons of similar sizes, the number of vehicles was adjusted (10 trucks in THW03 and 4 trucks in THW14) and the distance between the vehicles was manipulated (THW in the condition with large THW was equal to 1.4 s instead of 1.0 s).
- *The car following task:* it appeared in the second experimental study that participants were impeded in properly catching up with the LV. Parameters were modified in this study to ensure car following (lower acceleration and speed of the LV and speed cameras were removed).

- *The design of the study plan:* Two groups were formed to test for any carry-over effects and the first drive was the familiarisation drive.
- *The simulator type:* a medium-level simulator with side-views was used instead of a low-level simulator.
- *The duration time of the study:* participants were asked to drive for a total of 16 minutes instead of 6 minutes.

6.5.2 *Effect on lateral deviation*

There was a difference in the quality of lane keeping as measured by the parameter standard deviation of lateral position (SDLP) with regard to the scenarios with platoons keeping long or short THWs.

The variation in lateral position improved in condition THW03, which verified hypothesis 2. The results can be interpreted with the assertion made in Hancock and Desmond (2000) that an increase in task demand lead to the mobilisation of alertness and effort resulting in improved performance. In the present study, participants significantly reduced the distance to the LV in condition THW03. The shorter the distance to the LV, the higher is its influence on the driver. Thus, with a reduced distance, drivers need to be increasingly alert to anticipate any change in the LV's behaviour. The increased alertness has a positive impact on the lane keeping.

6.5.3 *Carryover effect*

Despite a trend in the expected direction, results do not support a carryover effect from one condition to the other (hypothesis 3) as there was no significant effect of group condition in the parameters analysed and especially in THW (mean, min.) and SDLP. A non-significant effect could be interpreted as a short-term effect of platoons, disappearing soon after the interaction with them. This interpretation is supported by the significant difference in mean THW found in the comparison between the period next to a platoon and the period between two platoons.

Another possible interpretation for the non-significant effect could be that the factor group was a between subject factor generating two groups of small size. Low statistical power suggests that the sample size was likely to have been too small to detect significant effects increasing the likelihood of a Type II error (erroneously failing to reject the null hypothesis).

A possible reason for a small effect size is that results showed the trend of a larger difference in mean THW between the two platoon conditions in Small-Large in comparison to Large-Small. Small-Large enlarged THW in the second condition THW14 to a greater extent than Large-Small decreased THW in the second condition THW03. The observed trend can be interpreted using social psychological influences. Firstly, it is important to remember that individuals are commonly influenced in their behaviour through social norms (Hume, 1739). Social norms are rules and standards that are understood by members of a group to guide and constrain social behaviour. They emerge from interaction with others, and, especially in conditions of uncertainty individuals often look for social norms (Cialdini, 2001). Watching others provides information about what is 'normal' in an ambiguous situation. Descriptive norms are derived from what people do in any situation. Some norms inform us about what is typically approved/disapproved (injunctive norms). In addition to commonly accepted rules of desirable behaviours, norms include rules forbidding unacceptable social behaviour (Cialdini, Kallgren & Reno, 1991). Furthermore, individuals have a strong need to enhance their self-concepts by behaving with consistency (Cialdini & Goldstein, 2004). The first simulator condition might favour the influence of descriptive norms: participants regulate their behaviour depending on the behaviour of other vehicles in traffic. Consequently, in the first drive participants starting with THW03 (Small-Large) would keep shorter THW than participants starting with THW14 (Large-Small). Keeping the same short THW than in the previous condition would make participants in Small-Large feel they are transgressing the norm because close following is an unacceptable social behaviour (injunctive norms), urging them to enlarge their THW. In contrast, there is less pressure on participants in Large-Small to change the car-following behaviour as it is acceptable to keep a large THW. Actually keeping the same THW makes participants in Large-Small act with consistency, which is important for their self-concept. This would

explain why participants in Large-Small change to a less extent their car-following behaviour in the second condition. The veracity of this interpretation should be investigated in further studies.

6.5.4 *THW over time*

Plotted over time, THW demonstrated a sinusoidal variation. Thus, drivers' THW fluctuated even if the speed of the lead vehicle was constant. This is apparently a manifestation of the acknowledged fact that drivers can be considered to behave as an operator in a complex monitoring and control task (Michon, 1985). According to the Action Point Model (Brackstone & McDonald, 1999, Brackstone & McDonald, 2007), drivers use perceptual threshold to regulate the distance toward the LV in a car-following situation. Even if the Action Point Model is one of the first to consider human factors, it is still not specific enough to explain the intra- and inter-personal differences in car-following behaviour. Understanding these differences, though, would enable a better understanding of the differences in behavioural adaptation observed across drivers and also how they affect safety.

A first step undertaken to understand the diversity in car-following behaviour was to establish a relationship between mean THW and standard deviation of THW. The result showed a significant correlation throughout the test drives. It can be argued that, depending on situational factors in the environment (e.g. traffic) or on driver (e.g. emotions), drivers will decide upon a THW they wish to adopt. The fluctuation of THW is thus dependent on the THW indeed adopted by drivers.

This finding can be interpreted through the perspective of the Action Point or psychophysical model, which postulates visual thresholds establishing a range within which drivers of vehicles would be unable to notice any differences in their dynamic condition and would seek to maintain a constant velocity. Car-following thus requires opening the gap to the LV until a perceptual threshold is reached, leading drivers to close the gap toward the LV until a perceptual threshold is reached. The accuracy in threshold perception decreases with increasing distance to the LV, offering one explanation as to why the periods of opening and closing gaps are longer when drivers are further away (Hoffmann & Mortimer, 1994). The other more simplistic explanation of the change in THW variation in relation to the change in mean THW is that there is more space for a fluctuation when the

adopted THW is large. Regardless of the origin for the difference in fluctuation, it is possible to see a duality of drivers' longitudinal control on the basis of THW over time:

- An open-loop control is represented by low THW frequencies. This control mode is associated with long term fluctuations and is triggered by external inputs under a driver's conscious control. The boundaries of the preferred THW range are triggering a change in acceleration. Specifically, drivers in this control mode are closing the gap to the lead vehicle until they consciously notice that they are too close, which will trigger a deceleration opening the gap. Drivers will open the gap until they notice that they are too far from the LV, which will trigger an acceleration closing the gap again.
- A closed-loop control is represented by high THW frequencies. Very small and automatic adjustments are represented here, which are expected to be subconsciously achieved by a driver. Rather than a range of preferred THW, drivers have a precise distance in mind and correct quickly and unconsciously any deviation of distances.

This concept is proposed here for the longitudinal control and has already been established in the lateral control of the vehicle (Donges, 1978; Schumann, Godthelp, Farber & Wontorra, 1993). Following Donges (1978), a model and a specific experimental set-up would help to differentiate the two processes.

A clear separation between the two processes would open new opportunities for analysis of the data. It is imaginable for instance that different criteria would apply for the different control processes: minimum THW is certainly more relevant in the open-loop control, whereas mean THW is more relevant in the closed-loop control.

So, it is concluded that the THW drivers decided to adopt influences the fluctuation of THW. It remains, now, to understand the factors that will affect drivers' THW selection. There is evidence in the literature that an important factor influencing drivers' THW is drivers' braking skills. Several studies show independence between the selected speed and adopted THW (Taieb-Maimon & Shinar, 2001; Van Winsum & Brouwer, 1997; Van Winsum & Heino, 1996). The present study showed, however, dependence between mean THW and THW maintained between vehicles in

traffic. In addition, results of the present study have shown that there is a difference between the drivers in the way they adapt their THW to the different traffic conditions. The drivers can broadly be separated into three categories: drivers who tend to keep a shorter THW, drivers who tend to keep a larger THW and drivers who seem to be very sensitive to variation in the environment and change their THW accordingly. Further studies need to examine whether drivers who change their THW maintain sufficient distance to retain safe control of the vehicle with respect to other traffic.

6.6 Conclusions

A very simplistic design was adopted in the third experimental study as no personality questionnaires were administered and there was no familiarisation drive. The reason for keeping the study short and thus cost-efficient was the doubt cast by the second study as no significant effect were found that would have eventually lead to relent the new path of research. The purpose of the third study was at first to reassure that the research direction was worthwhile.

The present car-following study successfully demonstrated that THW within platoons had an effect on drivers' tactic but also on drivers' safety if minimum THW is considered. Overall, drivers shifted toward the lead vehicle when THWs in platoons were short. A significant difference in maximum THW was also found and the amount of time spent under the critical threshold of 1 s was higher.

A comparison between this study and the previous study 2 in terms of the setting would shed some lights on the factors responsible for a behavioural adaptation of the non-platoon driver to occur. However, such an analysis is made difficult by the amount of parameters changed between the two experimental studies. Nevertheless, looking at the differences in vehicle types (cars vs trucks) can help understanding the underlying factors for behavioural adaptation of the non-platoon driver. The selection of cars to form platoons in the study 2 was justified by the assumption participants would be more likely to reproduce behaviour from other drivers that are similar to themselves. However, it was discussed at the end of study 2 that this similitude could also have caused participants not to allocate their attention to the visual channel with the platoons. Trucks were selected in this study as their salience could potentially increase the visual attention directed to the platoons.

Therefore, the employment of cars to form platoons actually enables to investigate the social mechanisms of behavioural adaptation of non-platoon drivers whereas trucks enable to investigate perceptual mechanisms. Significant results in the study 3 and non-significant results of study 2 could lead to interpretations in favour of perceptual mechanisms responsible for behavioural adaptation of non-platoon drivers. However, this interpretation is made difficult by the too large amount of different parameters in the settings of study 2 and 3. The difference between the two mechanisms needs to be investigated in a dedicated study plan.

An issue related to the study was that participants were explicitly asked to follow a lead vehicle, which generates an atypical car-following situation. It is of paramount importance to test the effect in a more representative car-following driving scenario. Another possible issue with this experimental study was that participants were lacking knowledge of their own braking skills in the simulator vehicle as they did not undergo a familiarisation drive before the treatment conditions. The familiarisation session would have offered the opportunity to learn simulator vehicle dynamic but also to get familiarise with the simulator environment (e.g. depth perception). As a consequence of the lack of training, participants might have decreased their THW more than if they were perfectly aware of their braking skills in the simulator vehicle. However, this might be mitigated by the fact that drivers had previous experience with TRL's driving simulator.

It seems that the influence of short THWs maintained in platoons is rather limited in time because there was a significant difference in THW depending on whether drivers are next to a platoon or between two platoons. In addition, results showed that there was no significant carryover effect from one condition to the other. However, the lack of significant carryover effect should be handled carefully as it could result from a small effect size and small sample size.

Another open question is whether drivers that adapt their THW in response to the prevailing traffic exceed their capabilities to maintain safe control of the vehicle. SDLP was significantly lower when drivers were next to platoons keeping short THWs. This supports the idea that drivers are mobilising efforts and alertness as a result of a reduced THW because they need to anticipate any reactions of the LV. Another result supports the fact that the reduction in THW is controlled namely there is no significant difference in the safety parameter minimum TTC. Nevertheless, it remains

possible that decreasing THWs may increase the risk of an accident. Further studies are therefore required to investigate whether drivers adapting their driving as a result of the THWs within a platoon are exceeding their capabilities and thereby increase their risk.

7 FOURTH EXPERIMENTAL STUDY: IMPLICIT CAR-FOLLOWING SITUATION

7.1 Introduction

The third study, reported in chapter 6, analysed the effect on adopted THW by means of an advanced driving simulator while driving in the vicinity of a platoon keeping short time headways (THWs). It was found that in the conditions set in the previous study, short THWs in platoons had an effect on drivers' tactic as measured with mean THW, and led to an increase in risk drivers are willing to take in terms of minimum THW and amount of time spent under the critical threshold of $THW = 1$ s. It was concluded that behavioural adaptation of the non-platoon driver to the short THWs kept in a platoon in the vicinity can occur. The results suggested that behavioural adaptation might affect the safety of the non-platoon driver. However, it is difficult to generalise the results to any car-following situation as the car-following scenario was generated by instructing participants to follow a lead vehicle (LV) and specifically not to lose track of the LV. Generally, car-following situations arise from traffic conditions and are rarely provoked by explicit formulated instructions. Hence, the car-following situation created in the second study was rather atypical. When drivers' velocity is determined by the velocity of a LV, the restriction in speed choice might be a frustrating experience for the driver and is susceptible to generate aggression (Shinar, 1998). The theoretical basis for Shinar's assumption (1998) was the classic aggression-frustration hypothesis (Dollard, Miller, Doob, Mowrer & Sears, 1939) containing two claims about the cause of aggression. Firstly, frustration conceptualised as the blocking or thwarting of some form of goal-directed behaviour, leads to some form of frustration. Secondly, aggression stems from frustration (Dollard et al., 1939).

Contrarily, car-following resulting from an explicit formulated instruction certainly generates a higher motivation in tracking the LV and probably less frustration. Motivation and emotions such as frustration and anger are generated by situational factors that have a transient effect on drivers' selected THW (see section 2.4.1.). The effect of short THWs in a platoon on non-platoon drivers' THW nearby might thus be affected by emotions and cognitive states generated by the driving situation.

However, we are expecting here that frustration will lead to close-following behaviour and that when drivers are surrounded by vehicles keeping short THWs, it will encourage drivers to keep an even shorter THW. Thus in spite of the different drivers' cognitive state, we were expecting the same result as the present experimental study as in the previous one.

As with the previous study, this fourth experimental study again used a driving simulator to assess behavioural adaptation of drivers' THW in response to the presence of platoons keeping short THWs in traffic. This time, car-following situations were generated implicitly by means of congested traffic in sections of the scenario. Participants were not explicitly asked to follow the LV but the traffic conditions resulted in a car-following situation in the vicinity of platoons. The configuration of the platoon was an independent variable with three levels (THW of 1.4 sec, THW of 0.3 sec or baseline condition); each participant experienced these three conditions in separate drives. Of interest was whether behavioural adaptation to the platoon configuration would occur and whether it would influence car-following as in the previous study.

Behavioural measures related to car-following were collected in order to evaluate any impact of platoons on car-following behaviour. In addition, subjective measures of personality related to driver behaviour were taken, as used in the second study (see Chapter 5, section 5.3.6, for a detailed explanation). Mental workload was also assessed using the NASA TLX scale.

7.2 Hypotheses

The aim of the present study was to investigate whether similar results to those found in the previous study were observed in the context of a non-explicit car-following situation. To do so, the traffic scenario was changed: participants had to drive in a congested traffic and time pressure was induced by the instruction. Participants were encouraged to make rapid progress in the simulated scenario as they were instructed to imagine that they were late for a meeting. Their progress was blocked by a slow vehicle that could not be overtaken. Such an environment may generate frustration and aggression occurring in the form of close-following (or even tailgating). It was expected that participants would be encouraged to keep even short THWs in condition THW03 as a result of the social environment (other cars keeping short THWs in platoons).

The hypotheses formulated were therefore similar. Hence, an influence of the presence of platoons maintaining short THWs on drivers' car following tactic and safety was hypothesised: non-platoon drivers adapt their behaviour to the short THWs maintained in a platoon by reducing significantly their mean THW (hypothesis 1 a) and minimum THW (hypothesis 1 b) (see Chapter 6).

If the hypothesis 1 a is verified, it is also hypothesised that the reduction in THW will be accompanied by a lower SDLP (hypothesis 2).

Similarly to the previous experimental study (Chapter 6), a factor was added in the fourth experimental study to find out if there was a carryover effect of one condition to the other. Finally, as it could not be excluded with certainty in the previous study that a carryover effect from one condition to the other could occur, a distinction between two groups was made again. It was expected that participants who were first confronted by platoons keeping short THWs will generally keep shorter THWs than participants first interacting with platoons keeping large THWs (hypothesis 3).

7.3 Method

7.3.1 *Participants*

Thirty participants (15 males, 15 females), aged between 28 and 68 years ($M = 48.47$ years, $SD = 11.97$ years) were recruited for the study from the TRL database. All participants held a valid full licence and had a mean of 29.3 years since licence acquisition ($SD = 12.09$ years). Participants had a mean estimated annual mileage of 11,733 miles ($SD = 8,107$ miles). None of the participants had taken part in any of the previous studies relating to the effect of short THWs within automated vehicles platoons on other drivers. A payment of £25 was made to each participant as compensation for their time and travel expenses.

7.3.2 *Material*

The experiment was performed using TRL's medium-fidelity driving simulator (please refer to Chapter 4, section 4.3.2 for a detailed description of the simulator).

7.3.3 *Driving environment*

Three driving scenarios were created using the driving simulation software SCANeR studio 1.1 from Oktal. The road type presented in the simulator was a straight left-hand three lane motorway. Walls bordering the road and trees were scattered alongside, clearly visible from the road point of view. Gantries were placed over the road at 2km intervals, displaying the authorised speed. The UK's speed limit on the motorway is 70 mph (DSA, 2011).

7.3.4 *Experimental design and procedure*

The basic principle behind the third experimental study was to investigate if there is any effect of THWs kept in platoons on the driver nearby in a non-explicit car-following scenario, where participants have not been asked to follow a particular lead vehicle (LV). However, a car-following situation was required to measure any influence of platoons on non-platoon drivers' THW and, as explained by Vogel (2003), car-following occurs when the speed of the driven vehicle is influenced by the speed of the vehicle travelling ahead.

To create a car-following situation, participants drove on a three-lane motorway on which the inside lane was occupied by platoons and the outside lane was intermittently closed due to temporary traffic management measures for roadworks. The lane closures restricted the motorway to the inside and middle lanes for three blocks of 5 km, each separated by 2 km sections where the outside lane was open. Consequently, within the roadworks section, participants were restricted to the middle lane.

To urge participants to maintain progress, they were given the instruction to imagine that they were late for a work meeting (APPENDIX G).

[...] "Imagine that you are late for a meeting. Regularly the right lane will be closed because of engineering work but the speed limit remains 70 mph." [...] [...]

A column of vehicles was placed in the middle lane and kept a regular and large distance between each other (THW of 6 s). This provided a sufficient gap for participants to re-join the middle lane after an overtaking manoeuvre. These vehicles were programmed to drive slower (57.79 mph) than

the speed limit on UK's motorways (70 mph). Therefore, within the lane closure sections, participants were likely to be impeded in their speed choice by the middle lane traffic. The presented scenario therefore promoted car following without having to tell participants explicitly to follow the LV. The procedure is illustrated in Figure 42.

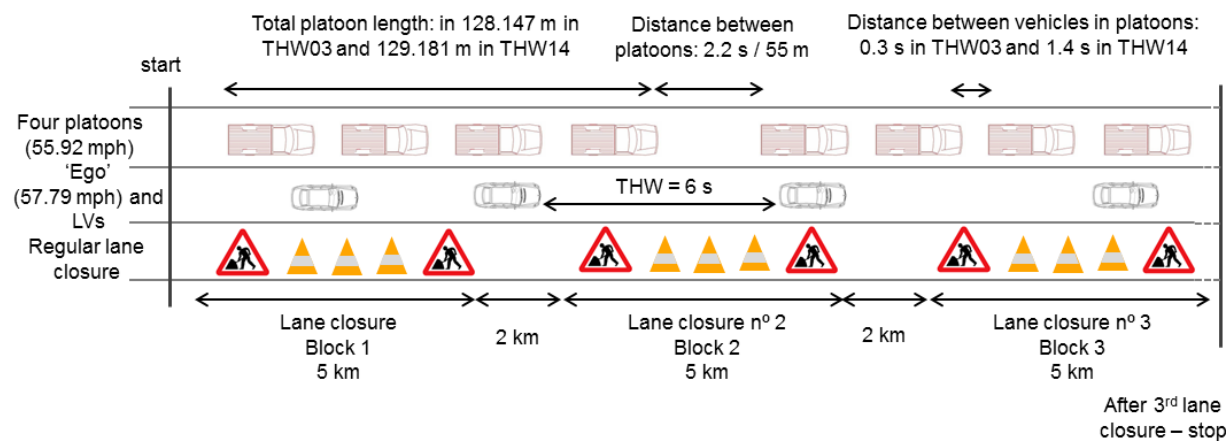


Figure 42 Schema of the study design in conditions THW14 and THW03

Unlike the previous studies, the scenario end point was based on distance not time; THW during the lane closure sections phase was of main interest for the analysis. However, the time spent in the lane closure sections did not vary substantially between participants as the LV dictated the speed achievable in the driven vehicle. In contrast, the time spent between the lane closures varied, depending on how quickly participants overtook vehicles in the middle lane.

Similar to the previous experimental studies, there were three drives in total: two drives were platoon conditions (THW03 and THW14) and one drive was a baseline drive (BL) (Figure 43). Platoons of vehicles in all the drives had the same length as in the previous study. The THWs between vehicles in the platoons represented a first factor. Contrary to the previous experimental studies, vehicles were present in the inside lane in the baseline condition (BL) as it was noticed in a pre-test that participants would overtake left, which was breaking traffic rules. To ensure that participants got into the car following situation, cars were added in this lane. The THW between these vehicles had to be large enough so that they would not be in a car-following condition, but close enough so that participants would not seize the opportunity to overtake on the left. THW between vehicles in platoon in BL was 2.1 s.




<p>Baseline (BL)</p> <p>Distance between vehicles in platoons: 2.1 s.</p>	
<p>THW14</p> <p>Distance between vehicles in platoons: 1.4 s.</p>	
<p>THW03</p> <p>Distance between vehicles in platoons: 0.3 s.</p>	

Figure 43 Road scenes from the simulated three-lane motorway during a lane closure, with platoons in the inside lane and LV in the middle lane.

The second factor was determined by the treatment order, as a carryover effect from one condition to the other was still suspected. Participants were randomly assigned to one of the groups following a counterbalancing plan. Prior to the experimental drives, participants performed a familiarisation session following the same procedure as the one presented chapter 4.3.1. The study design is presented in Table 10.

Table 10 Study design of the third experimental study

	<u>1st Drive</u>	<u>2nd Drive</u>	<u>3rd Drive</u>	<u>4th Drive</u>
Group Small-Large	Familiarisation	Baseline	THW 03	THW 14
Group Large-Small			THW 14	THW 03

7.3.5 Procedure

After reading and signing a consent form (APPENDIX A), participants were introduced to the simulator vehicle and told to adjust the seat and mirrors to their needs. Subsequently, participants received the written instruction for the study (APPENDIX G) and they were asked to complete a demographic questionnaire (APPENDIX F). If participants had no questions, the study could commence.

The study lasted for approximately one hour and participants had the opportunity to take a break after each drive. After having completed the study, participants were debriefed about the purpose of the study and they were informed that a carryover effect from the expected behavioural adaptation in the simulator to the real world could occur. They were instructed to be aware of their distance and keep at least a THW of 2 seconds to avoid this effect. Finally, they received monetary compensation for their time and expenses and were thanked for their attendance.

7.3.6 Behavioural measures

Driver behaviour data were collected by the simulator with a frequency of 20 Hz. THW was calculated using the speed and distance to next vehicle, a min, max and mean value could be established for every participant, condition and sub-condition (lane-closure blocks).

Participants had the opportunity to overtake the LV between each lane closure (after the 1st and the 2nd block). However, the 1st block was not included in the data analysis as it was considered as a

run-in to the trial. Only the overtaking manoeuvres after the 2nd block was considered for analysis. In preparing to overtake, drivers tended to close the gap to the LV and accept shorter THWs than those they would choose when following a vehicle. The last THW value before participants engaged in the overtaking manoeuvre was also used to analyse the impact on overtaking behaviour of short THWs kept in platoons. An overtaking manoeuvre was considered to have begun when all four wheels had left the lane.

7.3.7 *Subjective measures*

Participants were asked to fill in personality questionnaires in an attempt to establish a relationship between drivers' headway choice and these factors (APPENDIX F). The questionnaires included measures that have been shown to have a significant relationship with risk-taking behaviour in traffic or involvement in accident (as presented in detail chapter 2.3.5) (Ulleberg & Rundmo, 2003) (De Winter & Dodou, 2010): four of the facets from the NEO-Personality Inventory (Costa et al., 1992) (Anxiety, Anger, Excitement-seeking and Altruism), the Normlessness scale (Kohn & Schooler, 1983), driver behaviour questionnaire (DBQ) (Lawton et al., 1997) and Locus of Control (LoC) (Rudin-Brown & Parker, 2004). Additionally, demographic data (year, age, licence year and mileage) were also available. Mental workload was also assessed using the NASA-TLX scale. At the end of the experimental study, participants were asked if they recognised any differences between the three drives. This question was asked to see whether participants noticed any changes in the platoon features and especially if they noticed the short distances maintained by the vehicles in condition THW03.

7.3.8 *Data preparation*

For all drives and all participants, THW was plotted over time for each lane closure block. It was apparent that some participants first had to approach sufficiently close to the LV (Figure 44) to enter the typical close-following 'oscillation' with alternating periods of closure and separation relative to the LV. Furthermore, it emerged for certain participants that THW dropped by the end of each lane-closure block (Figure 45), demonstrating that these participants were preparing an over-

taking manoeuvre. It was decided that this did not represent typical car-following behaviour but was part of their preparation to overtake: drivers were ready to decrease the adopted THW below the limit of their preferred THW for car-following. The approaching behaviour and preparation to overtake had therefore to be excluded from the data because it was considered not representative of the behaviour under investigation; the effect of THW in platoons on car-following behaviour of the non-platoon driver. Systematic exclusion rules were required to cut the start (approaching behaviour) and the end (preparation to overtake) of the data that could be applied to every participant and to both lane-closure blocks. The difficulty in finding an appropriate pattern resided in the fact that each participant showed a different approaching behaviour and preparation to overtake. For instance, as shown in Figure 44, participant 23 in block 3 showed an approaching behaviour that expended over a rather long period of time but almost no preparation to overtake. Contrarily, participant 20 in block 2 (Figure 45) showed an obvious preparation to overtake and the approaching behaviour was barely apparent.

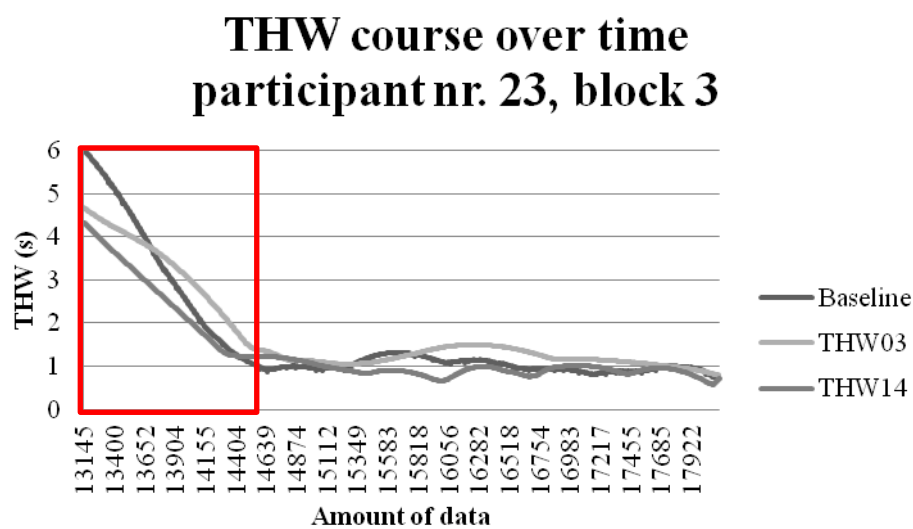


Figure 44 Example of one participant's THW showing an approaching behaviour (in the red box).

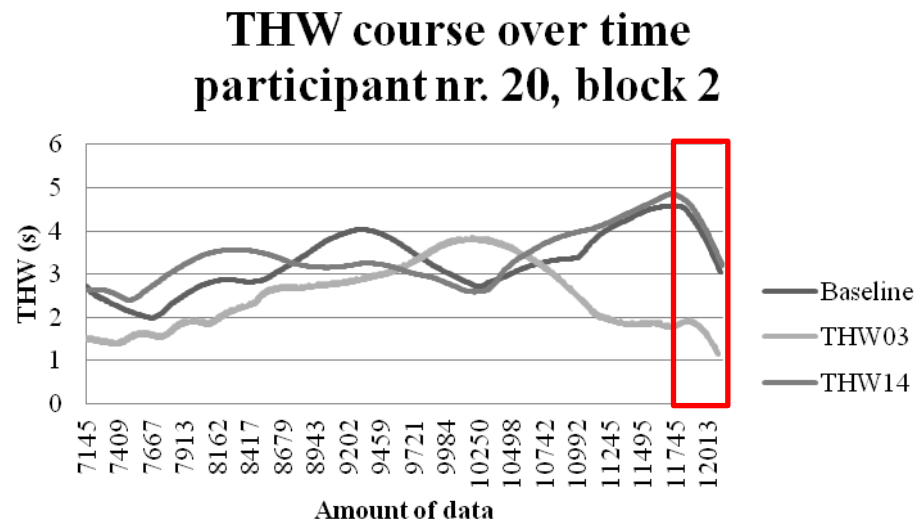


Figure 45 Example of one participant's THW showing a preparation to overtake (in the red box)

Different approaches were applied to cut the approaching behaviour and preparation to overtake. One method primarily considered the relative velocity between the driven vehicle and the LV; in particular, any sign changes in relative velocity – which means that drivers switched from a period of closing the gap toward the LV (negative relative velocity) to a period of opening the gap (positive relative velocity) and vice versa. Looking at the first sign change (from negative to positive relative speed) indicates when drivers enter the typical close following spiral (see section 2.4.2.2.) and looking at the last sign change indicates when the driver begins preparation for an overtaking manoeuvre.

The route was based on an X-Y coordinate system and was a straight road parallel to the X-axis. The X-coordinate of the driven vehicle therefore gives the position of the vehicle along the test route. The X-coordinates of the relative velocity sign change locations were noted with the aim of finding the X-coordinates where data can be cut at the beginning and end of the datasets. For each participant, each block and each condition, two types of X-coordinates were computed: one was determining the end of the approaching behaviour (in red in Figure 46) and the other determining the start of the preparation to overtake (in green in Figure 46).

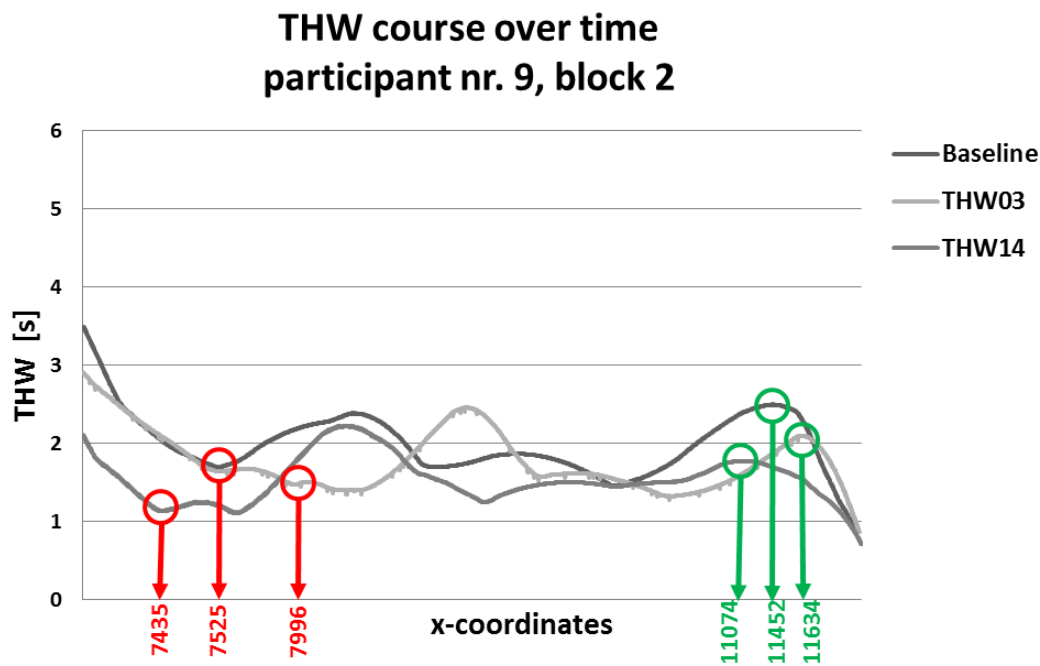


Figure 46 Procedure to determine a pattern to cut the data, exemplified with data from participant nr. 9, block 2

For some participants in some data-sets there is neither a sign of approaching behaviour nor of preparation to overtake. The lack of approaching behaviour is reflected in the data when the first sign change occurred only very late. Similarly, a lack of preparation to overtake appeared in the data when the last sign change of the data-set appeared very late. It would be thus justified to take these participants out of the data-set for the calculation of a pattern to cut the data. The procedure to do so was to consider participants, which first sign change appeared very late as outlier and similar for the lack of preparation to overtake: participants were considered as outlier when the last sign change appeared too early. Participants, who had a mean value for X-coordinates over 2 SD from the mean value, were considered as outliers and were also removed from the dataset. The reason for that criterion is that in a normal distribution, 2 SD from the mean account for 95.45 % of the data. The removed participants are shown in Table 11.

The subsequent step aimed to determine specific X-coordinate values to demarcate the start and end of the car-following region in each dataset. These two values needed to be chosen such that they could effectively extract the car-following regions for all participants and blocks with only few misclassifications. For this purpose, three methods were applied:

- A *conservative* method considered the maximum coordinate to determine the end of the approaching behaviour and the minimum coordinate to determine the start of the preparation to overtake across all participants and blocks. The advantage of this method was that it completely erased the approaching behaviour and preparation to overtake from the data-set. However, applying these boundaries resulted in the exclusion of a large proportion of the data (e.g. start: $X = 10075$ m; end: $X = 10474$ m – this 399 m region represents less than 10% of a 5 km lane closure block).
- An *average* method consisted of computing the mean of all the coordinates representing the first and the mean of all the coordinates representing the last sign change. This would not cut enough data for participants showing a long approaching period and preparation to overtake but had the benefit that it retained a greater proportion of the data for analysis (e.g. start: $x = 7841$ m; end: $x = 11710$ m – this 3869 m region represents more than 75 % of a 5 km lane closure block).

Table 11 Overview of 1) the mean values cutting both the start and end of the data-set resulting from the two methods average and conservative and 2) outliers.

Average method		Conservative method		Outlier 2SD	
Start	End	Start	End	Start	End
7840.97	11709.55	10075	10474	[Vp14, THW03, block 1]	[Vp20, THW14, block 2], [Vp30, BL, block 2]

- A third method cut the approaching behaviour and the preparation to overtake, separately, for each participant. The third method was based on a data representation often used in Action Point Models (Brackstone & McDonald, 1999; Brackstone & McDonald, 2007). As presented in detail in chapter 2, it consisted of plotting the relative speed and spacing distance to the LV. Figure 47 exemplifies the resulting close following spiral, taking as an example the data from one participant.

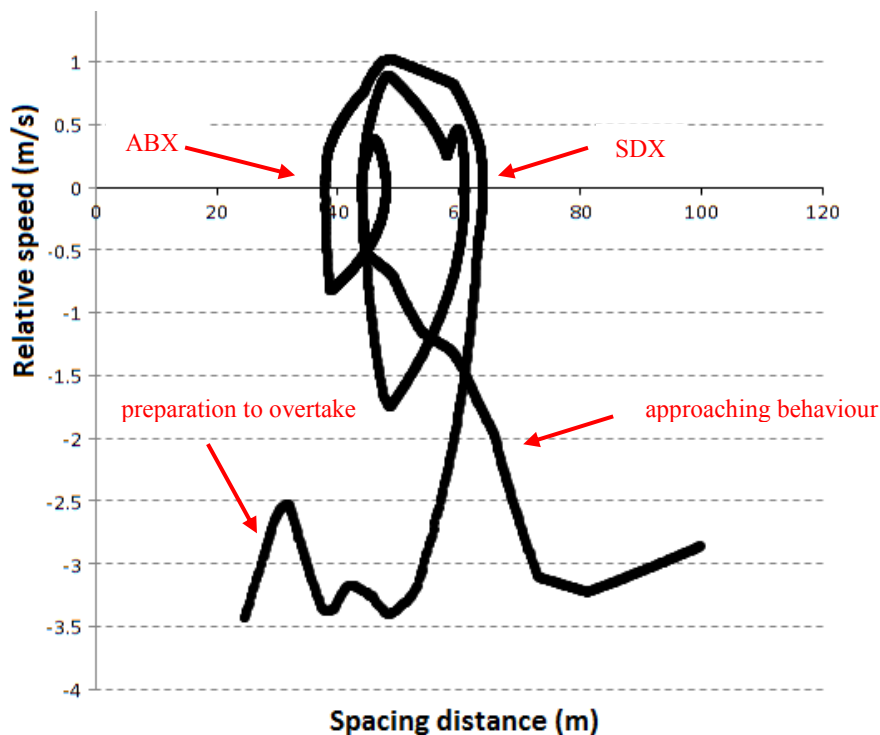


Figure 47 Car-following 'spiral' from participant 9, Baseline, block 3

According to the Action Point Model, the inter-vehicle distance and relative speed are measures that characterise car-following behaviour. However, it is very difficult for a driver to maintain a constant distance. When drivers feel they are perhaps drifting too close or too far away or that a clear relative speed has developed, they will try to compensate by either accelerating or decelerating. In this close-following spiral, ABX is the distance headway minimum and SDX is the distance headway maximum; each characterised by a zero relative speed difference between the driven vehicle and the LV (Brackstone et al., 2002). ABX appears after a decreasing distance when the relative speed changes from the negative to the positive. Contrarily, SDX appears after a distance increase at the point where the relative speed changes from positive to negative.

As ABX and SDX typically represent car-following behaviour, considering only these values for the data analyse enables filtering of any spurious data such as approaching behaviour and preparation to overtake (see Figure 47).

The THW values corresponding to either ABX or SDX were computed. An average value was calculated with all the obtained THW values for ABX and SDX. The obtained values were then

averaged and the following parameters were extracted: ABX (mean, min), SDX (mean, min), mean (ABX-SDX).

As none of the three data extraction methods provided an optimal solution to cut the data, subsequent analyses were conducted using the three different datasets generated by applying the three different exclusion methods (conservative, average and ABX-SDX).

7.3.9 Data analysis

Data obtained from the Baseline were considered separately from those for the platoon conditions as the Baseline was a control condition to verify that the two groups were comparable using independent t-tests. The analysis of the data in platoon conditions was conducted with a 2×2 mixed ANOVA (within subject design: platoon conditions, between subject design: groups).

7.4 Results

The difference in mean THW between the groups Small-Large and Large-Small in the Baseline was non-significant, independent from the method used to cut the data. Results of independent t-test are presented in Table 12. The same patterns of results are found for minimum THW as shown in Table 13.

Table 12 Results of the independent t-test on mean THW during the lane closure (block 2 and 3) in Baseline drive for Small-Large and Large-Small THW groups across data exclusion methods.

Measurement	t	df	p
Average	-1.18	28	.25
Conservative	-1.18	28	.25
ABX-SDX	-1.35	28	.19

Table 13 Results of the independent t-test on min THW during the lane closure (block 2 and 3) in Baseline drive for Small-Large and Large-Small THW groups across data exclusion methods.

Measurement	t	df	p
Average	-1.00	28	.33
Conservative	-.90	28	.38
ABX-SDX	-1.18	28	.25

7.4.1 Mean THW during the lane closure

A 2×2 mixed ANOVA (within factor: two platoon conditions THW03 and THW14; between factor: two order groups Small-Large and Large-Small) was carried out on each of the data-set (average, conservative and ABX-SDX). The results yielded neither a significant effect of THW nor a significant effect of order or significant interaction effects. Mean scores and standard deviations are presented in Table 14 and results of the statistical analysis are presented Table 15.

Table 14 Mean THW and standard deviations in treatment conditions for all the data-sets (N = 30)

Data-set	THW03		THW14	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Average	1.81	.93	1.79	.91
Conservative	1.76	.92	1.78	.91
ABX-SDX	1.64	.90	1.67	.87

Table 15 Results of the 2×2 mixed ANOVA for mean THW in the data-sets average, conservative and ABX-SDX (N = 30)

Effect		F	df	p	eta	power
Average	THW	.09	1	.76	.00	.06
	Order	1.40	1	.25	.05	.21
	THW \times Order	2.20	1	.15	.07	.30
Conservative	THW	.12	1	.73	.00	.06
	Order	2.28	1	.14	.07	.31
	THW \times Order	.84	1	.37	.03	.14
ABX-SDX	THW	.14	1	.71	.00	.07
	Order	1.10	1	.31	.10	.20
	THW \times Order	3.05	1	.09	.04	.40

7.4.2 Minimum THW during the lane closure

A 2×2 mixed ANOVA (within factor: two platoon conditions THW03 and THW14; between factor: two order groups: Small-Large and Large-Small) was carried out on each of the data-set (average, conservative and ABX-SDX). As with mean THW, results revealed neither a significant effect of THW nor a significant effect of Order and no interaction effects reached significance. Mean scores and standard deviations are presented Table 16 and results of the statistical analysis are shown in Table 15. As there was no significant effect of the mean THW and the min THW, the analysis of SDLP was unnecessary.

Table 16 Averaged minimum THW scores and standard deviations in the treatment conditions for all the data-sets (N = 30)

Data-set	THW03		THW14	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Average	1.07	.68	1.12	.72
Conservative	1.12	.71	1.19	.71
ABX-SDX	1.04	.64	1.07	.72

Table 17 Results of the 2×2 mixed ANOVA for minimum THW in the data-sets average, conservative and ABX-SDX (N = 30)

Effect		F	df	p	eta	power
Average	THW	1.03	1	.32	.04	.17
	Order	.58	1	.45	.02	.11
	THW \times Order	.77	1	.39	.03	.14
Conservative	THW	2.09	1	.16	.07	.29
	Order	.82	1	.37	.03	.14
	THW \times Order	.63	1	.43	.02	.12
ABX-SDX	THW	.28	1	.60	.10	.08
	Order	.53	1	.47	.02	.11
	THW \times Order	1.46	1	.24	.05	.21

7.4.3 Minimum THW before overtaking

Generally, participants showed a great propensity to overtake the LV. It occurred only rarely that drivers did not overtake the LV in the regions between lane closures: two participants never took the opportunity to overtake the LV (participants n° 4, 5, 10 and 30), some others did not overtake in THW14 (participants n° 16 and n° 23). The averaged minimum THWs just before engaging in an overtaking manoeuvre are very similar in the two platoon conditions (THW03: $M = .60$, $SD = .51$ and THW14: $M = .60$, $SD = .52$). The dependent t-test showed no significant difference in the averaged value between the two conditions, $t(23) < .05$, $p = .99$.

7.4.4 Subjective data

Correlations were computed to examine the relationship between personality constructs measured by the questionnaires administered to participants and participants' mean THW. As the assumptions of normality required to conduct Pearson's r were violated for some of the variables, the cor-

relations were computed with Spearman's rho. Table 18 shows the Spearman's rho coefficients of variables that showed significant correlations.

The results showed a positive and significant medium correlation according to Cohen's definition (1992) between the participants' estimated annual mileage and mean THW in THW03 in the average dataset ($\rho = 0.37, p < .05$) and ABX-SDX dataset ($\rho = 0.36, p < .05$) and a positive and near significant medium correlation in the conservative dataset ($\rho = 0.34, p = .08$). This suggests that higher mileage drivers tended to adopt the higher THWs to the LV in the THW03 condition.

Furthermore, significant medium correlations between the DBQ's category Highway Code Violations (HCV) and mean THW in THW14 were observed in the average dataset ($\rho = -0.37, p < .05$) and ABX-SDX dataset ($\rho = -0.39, p < .05$). The correlation was medium and marginally significant in the conservative dataset ($\rho = -0.32, p = .09$). The results suggest that a higher propensity to commit violation as reported by the HCV scale is associated with the adoption of smaller THWs.

In addition, there were significant medium correlation observed between results of the Normlessness scale and mean THW in all the datasets: average ($\rho = -0.37, p < .05$); conservative ($\rho = -0.38, p < .05$) and ABX-SDX ($\rho = -0.39, p < .05$). Thus, the higher scores on normlessness were associated with shorter mean THWs.

Finally, Anxiety showed a medium and significant correlation with the mean THW in THW14 in the ABX-SDX dataset ($\rho = 0.37, p < .05$).

Table 18 Spearman's rho correlation between personality characteristics/ attributes and mean THW in different traffic conditions and data-sets (* $p < 0.05$, ** $p < 0.01$) (N = 30)

Effect		Annual mileage	DBQ-HCV	Normlessness	Anxiety
Average	BL	.31	-.20	-.24	.29
	THW03	.37 *	-.26	-.22	.28
	THW14	.22	-.37 *	-.37 *	.30
Conservative	BL	.30	-.21	-.24	.28
	THW03	.33	-.22	-.17	.27
	THW14	.20	-.31	-.38 *	.30
ABX-SDX	BL	.30	-.22	-.23	.33
	THW03	.36 *	-.25	-.23	.36
	THW14	.19	-.39 *	-.39 *	.37 *

7.4.5 Platoon perception

After the experimental trial, participants were asked if they recognised any differences between the three drives. The results reported Figure 48 show a trend of participants being more aware of the small distances maintained in platoons in the group Large-Small. However, there was no significant association between the group and the awareness in change of THW [$\chi^2 = .54$, $p = .46$].

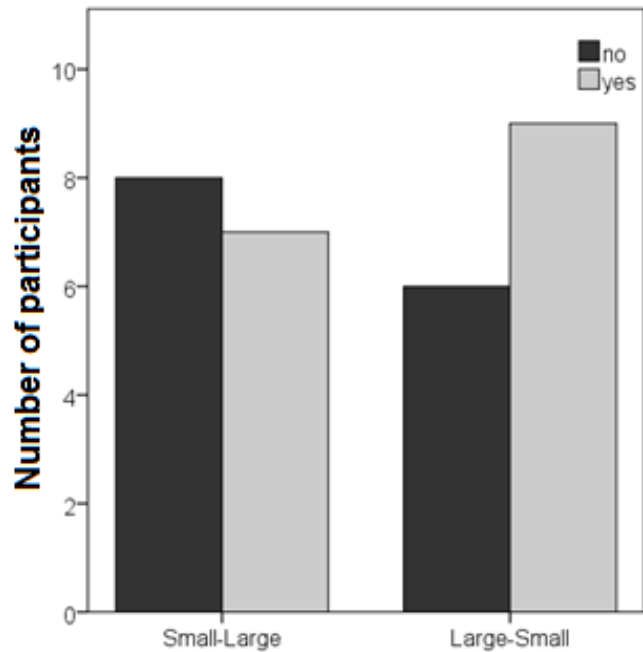


Figure 48 Bar chart to show a count of the responses to the question “Did you notice the difference between the three active drives?” across the two order groups (Small-Large and Large-Small) (N = 30)

7.4.6 Workload

The workload scores of this experimental study are shown in Figure 49. A dependent t-test was conducted in each dimension to compare the scores between the two platoon conditions. There was no readjustment of the α -value as the dimensions of the NASA-TLX are independent. There was a significant effect in the dimension Effort [$t(29) = 2.19, p = .04$]. Two others dimensions were marginally significant: Physical demand [$t(29) = 2.00, p = .06$] and Temporal demand [$t(29) = 1.74, p = .09$]. No other significant effects were found.

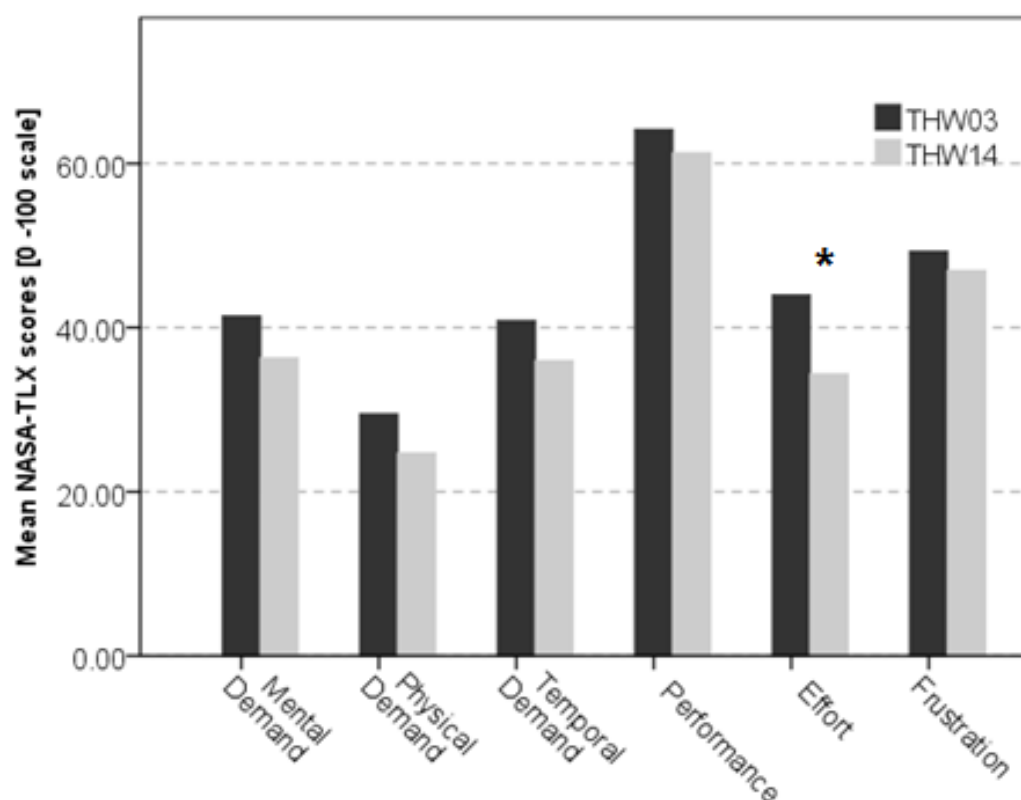


Figure 49 Scores of the NASA-TLX in the two conditions THW03 and THW14 (N = 30)

7.5 Discussion and conclusions

The aim of the study was to investigate whether the results found in the previous experimental trial (chapter 6) could be found in a similar car-following experimental set-up in which the instruction were modified such that participants were not instructed to follow the LV. The scenario took place on a three-lane motorway whereby the inside lane was occupied by platoons of vehicles and the outside lane was regularly closed because of regular blocks of engineering works. A row of vehicles driving slightly slower than the speed limit were scattered along the middle lane so that participants were always driving behind a car. To motivate participants to stay behind the LV (and make measurement of THW possible), they were told to imagine that they were driving to a meeting and were running late. They had the opportunity to overtake between the lane closure blocks.

The aim followed by this scenario was to reproduce a realistic car-following scenario where drivers are forced to follow a LV as a result of traffic conditions and not because of any explicit instructions. The frustration-aggression hypothesis (Berkowitz, 1989) suggests that when individuals' goals are blocked, frustration follows as a natural consequence. In addition, different studies have

reported the link between congestion and aggression disposition (Deffenbacher, Huff, Lynch, Oetting & Salvatore, 2000; Shinar, 1998). The scenario resulted in participants' progress blocked by a slow vehicle that could not be overtaken. Such an environment certainly generates frustration and aggression, exacerbated by time pressure, occurring in the form of close-following. It was hypothesised that in THW03, drivers may be more inclined to follow with a short gap as a result of the social influence of the vehicles in the surrounding.

However, contrary to expectations, the results found in the present study were different from the results found in the previous one: there was neither a significant effect of the treatment on drivers' tactic nor safety. Low statistical power suggests that the sample size was likely to have been too small to detect significant effects increasing the likelihood of a Type II error (erroneously failing to reject the null hypothesis). Furthermore, as there was a consistency in the results for being non-significant across the different data-sets, the difference between them can hardly be discussed.

Comparing the setting of this study with the previous one that returned significant results can help understanding the lack of significance of the results. One of the main differences between the two studies was the instruction. In contrast with the previous experimental study, participants were not explicitly told to follow a lead vehicle. The car following situation was generated by the congested traffic and the instruction inducing time pressure. Participants' cognitive load was certainly higher in this study as compared to the previous one as a result of time pressure combined to the congested road. It can be interpreted that the lack of significance in the results could have been caused by a visual tunnelling as a result of cognitive load. Visual tunnelling could have had as a consequence the focus on the task and the blinding out of surrounding elements, not immediately useful to accomplish the task. There is a support in the literature for this phenomenon. In a number of experiments it appears that with increasing foveal load, visual tunnelling occurred, resulting in a higher reaction time to more peripheral stimuli (Miura, 1986; Williams, 1985, 1995). Specifically, the study conducted by Miura (1986) has demonstrated that there is a reduction of the visual field of view with higher complexity of the driving task (higher traffic density). Moreover, there is evidence in literature for the relationship between a reduction in the field of view and an increase of workload (Jahn et al., 2005; Martens & Van Winsum, 2000; Olsson & Burns, 2000). Hence, it is

possible that the lack of significant differences between the treatment conditions results from drivers' tunnelling view and was generated either by the frustration scenario (congestion) and/or because of foveal load. Another explanation for the lack of significant effect of the treatment on drivers' tactic and safety could be the small amount of time spent next to platoons. The 5 km blocks were probably too short and did not allow sufficient time for the drivers to adapt their behaviour to the presence of platoons keeping short THWs.

The results of the NASA-TLX showed generally a higher score in THW03 and precisely a significant difference in the dimension Effort as well as marginal significant differences in the dimensions Temporal Demand and Physical Demand. These results indicated that, although shorter THWs in platoons had no influence on drivers' behaviour, they appeared to increase drivers' workload. The higher cognitive load in condition THW03 can be interpreted as an effect of increased foveal load due to the higher traffic density generated via smaller THW between vehicles in the platoon.

In contrast with the behavioural results, analysis of the subjective data yielded some significant results. Some of the constructs measured via the questionnaires were significantly correlated with the mean THW. Especially noteworthy was the correlation between the DBQ's facet HCV (Highway Code Violation) and mean THW. When participants reported to be prone to Highway Code violations, they tended to keep a shorter THW in condition THW14. This HCV facet includes items such as "drive especially close to the car in front as a signal to its driver to go faster or get out of the way". Similarly, there was a significant medium correlation in THW14 between the normlessness scale and mean THW. Individuals scoring high on this scale are assumed to have low barriers towards socially unapproved behaviour. Results showed that the higher participants scored on this scale, the smaller were their THWs. However, one can wonder why only THW14 was affected by a medium and significant correlation between mean THW and the DBQ-HCV and normlessness scale. Furthermore, it is worth noticing that anger did not significantly correlate with the THW. In addition, it appeared that there is a significant medium correlation between THW03 and the annual mileage in the average and ABX-SDX data-set.

At the end of the trial participants were asked whether they perceived the difference between the platoons in the two treatment conditions. Although the difference was not significant, it shows the

tendency that participants were more aware of the short THWs between vehicles in platoon when they were first confronted to the platoons with higher THW. It seems that the order of presentation has an impact on the perception but, of course, further research is required to strengthen this assumption.

This study was the last one in a series aiming at investigating whether UVDs adapt their car following behaviour to the short THWs held in platoons. The next chapter offers an overview of the different experimental studies conducted within this work before outlining the research contribution of the work.

8 DISCUSSION

8.1 Summary of the experimental studies

The major aim of this work was to investigate whether unequipped vehicle drivers (UVDs) adapt their car-following behaviour to the short time headways (THWs) maintained within platoons. Table 19 gives an overview of the objectives targeted in Chapter 1.

Table 19 Overview of the objectives targeted in Chapter 1

		Study 1	Study 2	Study 3	Study 4
Objective 1	Develop a <u>method</u> in terms of scenario and definition of relevant dependent variables to analyse the behavioural adaptation of UVDs to the short time headways (THWs) maintained in a platoon of electronically coupled vehicles.	✓	✓	✓	✓
Objective 2	Investigate which parameters of the <u>environment</u> are favourable to the emergence of behavioural adaptation of UVDs to short THWs observed in platoons.	✓	✓	✓	✓
Objective 3	Investigate which <u>inter-individual characteristics</u> are responsible for differences in the way drivers adapt to the short THWs in platoons.		✓		✓
Objective 4	Investigate whether drivers are willing to <u>keep a THW smaller than their preferred one to conform to a norm</u> established by the platoon.		✓		
Objective 5	Explore and <u>identify key tactical differences in the processes of car-following</u> to understand inter- as well as intra- heterogeneity in car-following behaviour.			✓	

Until now, studies have neglected to address the behavioural adaptation of the UVDs. Therefore, the methods applied in this thesis could only draw on previous experience from indirectly relevant research. In addition, the challenge of the research aim pursued in this work was that the emergence

of behavioural adaptation of UVDs can be influenced by a wide range of variables. Each of the four studies conducted in this work sought to improve understanding of the variables that influence the occurrence of the phenomenon. Table 20 gives an overview of the four studies, outlining the method and main results.

Table 20 Overview of the studies

Study No.	Method	Main results
1	<ul style="list-style-type: none"> - Mid-level car simulator (N = 12) - Independent variable (IV): THW in platoons - Task = car-following induced by instructions. 	<ul style="list-style-type: none"> - Participants spent a marginally significantly longer time below the threshold of 1s in the condition with short THWs in platoon.
2	<ul style="list-style-type: none"> - Low-level car simulator (N = 42) - IV1: THW in platoons (of cars) - IV2: time point in which preferred THW was measured. - Task = car-following induced by instructions. - Drivers' characteristics were assessed via questionnaires. 	<ul style="list-style-type: none"> - Reliability and validity of preferred THW - In platoon conditions and especially in when the THWs were short, drivers were very close on average to the limit of their preferred THW. - Some personality attributes were correlated with adopted THW.
3	<ul style="list-style-type: none"> - Mid-level simulator (N = 30) - IV1: THW in platoons (of trucks) - IV2: treatment order (LargeSmall vs SmallLarge) - Task = car-following induced by instructions. - Variables changed as compared to the previous trial: the exposition time, the platoon conspicuity, apparatus, acceleration of the LV. 	<ul style="list-style-type: none"> - Behavioural adaptation was observed, affecting drivers' tactic and safety. - Evidences for the inter- and intra-personal differences in car-following behaviour were found.
4	<ul style="list-style-type: none"> - Mid-level simulator (N = 30) - IV1: THW in platoons (of trucks) - IV2: treatment order (LargeSmall vs SmallLarge) - Task = car-following induced by traffic condition (congested traffic). - Drivers' characteristics were assessed via questionnaires. 	<ul style="list-style-type: none"> - No significant differences between the two platoon conditions were found. - The lack of significance was interpreted as the result of a tunnel view generated by the tasks' frustration.

8.2 Research contribution

From the studies reported in this work, it is possible to draw the general conclusion that behavioural adaptation can occur, depending on the circumstances of the interaction between UVDs and automated vehicles. This section describes in more detail how each of the objectives was addressed. In addition, the implications of the findings for the research community and for practitioners will be discussed.

8.2.1 *Contribution according to the original PhD objectives*

Objective 1: Development of a method

Considering the novelty of the research aim, it was not possible to directly build on any previous method and it was thus an objective to develop a suitable method. In general, a method contains: the selection of a research instrument, the selection of independent and dependent variables as well as the design of a study. Each of these points is discussed in this section.

- The first considerations were directed toward the research instrument selection. A driving simulator appeared to offer the most appropriate approach (see Chapter 3). However, different options are available within this type of apparatus (from low-level to high-level simulators), each having its own advantages and disadvantages (see Chapter 3). Based on the results obtained in this work, it can be suggested that higher fidelity simulators with side views are necessary to explore the effect of driver behaviour in relation to surrounding traffic as it increase the visibility of the THWs within platoons (Chapter 5).
- Furthermore, the treatment consisted of varying the THW of vehicles present in platoons (short to long THW). Only two conditions were chosen here for the reason justified in Chapter 5: platoons were keeping either a THW that was short ($\text{THW} = 0.3 \text{ s}$) or long ($\text{THW} = 1.0 \text{ or } 1.4 \text{ s}$). In a baseline condition, there were no platoons. The purpose and design of the baseline condition was developed through the different research studies. It enabled comparisons of a scenario without the influence of platoons with a scenario with the

presence of platoons (Chapter 5) or the baseline was used to compare between group conditions (Chapters 7 and 8).

- Dependent variables were selected to explore how the treatment had an impact on UVDs. Quantitative performance data were used as indicators for impact on driver tactical behaviour (e.g. mean adopted THW), but also as indicators for impact on driver safety (e.g. minimum adopted THW, percentage of THW spent under the critical threshold of 1s and minimum TTC) and workload (SDLP). Subjective data generally aimed at informing about drivers' inter-individual characteristics and to see whether these affected behaviour. The rationale for the use of these variables was detailed in Chapters 4, 5 and 7.
- In order to measure any changes in driver behaviour, a scenario was required where participants would have to follow a LV at a sufficiently close distance. This last point is important, as the results of study 2 (Chapter 5) were interpreted as not significant; one of the reasons could have been that participants could not catch up with the LV.
- Car-following behaviour can be generated either through instructions or through traffic and the selection of approach is not without impact on the behavioural adaptation effect. In this research, no significant results were found in study 4 (Chapter 7) when car-following was induced through congestion as compared to study 3 (Chapter 6) where significant results were found, and in which car-following was generated by instructions. It was therefore interpreted that the instructions could have implications for the difference in results.
- A method of limits was successfully implemented to assess participants' minimum preferred THW (see Chapter 5 and 6). Comparing the two parameters 'minimum adopted THW' and 'preferred THW' informed about risks taken by drivers. Results showed a consistency of preferred THW, whereas there was a significant difference in adopted THW values throughout the conditions, supporting the idea of there being two distinct constructs.
- A within-subject design was chosen throughout this work as it enabled a smaller sample size due to lower variability between groups as compared with a between-subject design. However, the danger in having groups undergoing both platoon conditions is that a carry-

over effect can occur. Employing a between-subject design would have eradicated any potential carry-over effect but it was also of interest to measure whether any carry-over effect did exist. To do so, a group variable was introduced depending on the platoon treatment order (Chapter 6 and 8). None of the results showed the existence of a carry-over effect. The presence of a carry-over effect would have informed about the lasting effects of behavioural adaptation. It can be interpreted that a within-subject design can be used in this area because the carry-over effect was not found to be significant.

Objective 2: Parameters favourable to the emergence of behavioural adaptation

Objective 2, on the parameters favourable for behavioural adaptation, was not investigated directly through experimental manipulation but some evidence emerged through the experimental studies conducted in the thesis. As the parameters have not been included in the design of the studies, they have to be considered with caution and further experimental studies are required to strengthen these conclusions.

- There was no significant behavioural adaptation in the second study (Chapter 5) when it appeared that participants were impeded in properly catching up with the LV. Car following is a requirement for behavioural adaptation to occur.
- There was a behavioural adaptation effect in the third study (Chapter 6) for THW when there was a high motivation for drivers to follow the LV and participants had no constraints in catching up with the LV.
- There was no behavioural adaptation when the car-following situation was generated by congested traffic (Chapter 7). It was interpreted that congestion was a source of frustration resulting in a tunnelling view. Consequently, participants probably paid little attention to the vehicles in the adjacent lane.
- It appeared that the duration of interaction (time exposure) with a platoon affected the extent of behavioural adaptation (Chapter 5). In the fourth study (chapter 7), the 5 km blocks may not have been long enough to allow behavioural adaptation given they include overtaking lead-in.

Objective 3: Influence of inter-individual characteristics

- Some evidence for inter-individual characteristics were found but these did not appear consistently throughout the trials.

Objective 4: Conformity to the new norm established by platoons keeping short THWs

- Participants' minimum adopted THW was very close to their minimum preferred THW in the two platoon conditions, especially in THW03, but did not fall below it. It can be concluded that exposure to platoons can lead UVDs to drive closer to their limits, in terms of THWs.

Objective 5: New knowledge acquired on car-following behaviour

- One achievement made here was the demonstration of the linear relationship between the mean THW and the SD of the mean THW made in Chapter 6. This means that the closer a driver is to a lead vehicle (LV), the smaller are their fluctuations in THW around a mean value. Contrarily, the larger the mean THW, the higher the fluctuations are around this mean value. Despite the simplicity of this result, the relationship does not appear to have been previously reported in the literature. The fluctuations around the mean THW varied between different drivers, but also across driving conditions for (some) individual drivers. It is not clear yet which underlying factors are responsible for the variability. However, two distinct processes of car-following (open- and closed-loop) were suggested and this represents a possible opportunity for further research.

8.2.2 Implications of the research

This thesis provides a contribution to research on behavioural adaptation. As presented in the literature review (Chapter 2), theories explaining the origins of behavioural adaptation are motivational models (risk and workload models) and trust theories. Wilde's homeostasis theory (1982b) states that drivers always try to maintain the same level of acceptable risk by adjusting behaviour variables such as THW or speed. Moreover, in the "zero-risk theory" from Näätänen and Summala (1974), a driver is considered to act to control the risk level only when the risk exceeds a safety margin. Likewise, in Fullers' Risk Allostasis Theory (2008), drivers adapt their behaviour so that the task demand does not exceed their capabilities.

Arguably, contributing factors in behavioural adaptation considered in this thesis were social and perceptual mechanisms. Since the driver is not alone on the road, a range of different norms are proposed to dictate drivers' behaviour as modelled in the TPB (Ajzen & Madden, 1986) and its extension (De Pelsmacker & Janssens, 2007). The range of studies conducted in this work demonstrate the social impact of other drivers in the surrounding of the driver, which is in accordance with the 'descriptive norm' as described by De Pelsmacker and Janssens (2007). In addition, previous studies found that drivers, who were engaged in platoons holding short THWs, adapt their behaviour in keeping short THWs in the subsequent manual drive (Skottke, 2007). Results were interpreted as the effect of a change in the frame of reference: after a platoon drive with very short THWs, 'normal' THWs appear very large leading drivers to reduce the THW they would normally keep. As visual processes are seen as responsible for behavioural adaptation, other drivers at risk would be UVDs who are not engaged in a platoon but driving in the vicinity of a platoon with short THWs clearly visible to them. At this stage, it is still unclear though whether behavioural adaptation of non-platoon drivers to short THWs in platoons is the result of a combination of social and perceptual mechanisms or if one of the mechanisms is predominantly influencing behavioural adaptation. Results of study 2 reported non-significant effect in car following parameters between two platoon conditions. In contrast, study 3 reported significant difference in these parameters between the two platoon conditions. One of the differences in the setting parameters between the two studies was the type of vehicles forming a platoon. The selection of cars to form platoons in the study 2 was justified by the assumption participants would be more likely to reproduce behaviour from other drivers that are similar to themselves. Trucks were selected in study 3 as their salience could potentially lead participants to increase their visual attention to the platoons. The employment of cars to form platoons actually enables to investigate the social mechanisms of behavioural adaptation of non-platoon drivers whereas trucks enable to investigate perceptual mechanisms. Significant results in the study 3 and non-significant results of study 2 could lead to interpretations in favour of perceptual mechanisms responsible for behavioural adaptation of non-platoon drivers. Results of study 2 (chapter 5) are not in favour of social mechanisms. The method of limits was developed and implemented in study 2 to assess preferred THW and to investigate whether drivers are ready

to keep a shorter THW to conform to the new norm established by platoons (section 5.1). Thus far, in the conditions tested within this work, there was no evidence for a strong influence of the norm leading drivers to adopt a shorter THW than they wished to match the THWs of EVDs in the surrounding (Chapter 5). There was evidence, however, that drivers were driving closer to the minimum threshold of their preferred THW. It is still unclear whether behavioural adaptation of UVDs is arising as a result of either perceptual or social mechanisms, or perhaps a combination of the two. However, the results together show that the underlying factors involved in the behavioural adaptation of the UVDs differ from the risk theories so far acknowledged explaining behavioural adaptation. Instead of changing behaviour as a result of a change in perceived risk, it seems that drivers are willing to accept more risk (consciously or not) as a result of the influence from other vehicles' behaviour.

Results of study 1 (Chapter 4) showed a marginally significant increase in time spent under the critical threshold of 1s in the drive when vehicles in platoon kept a short THW. Results of study 2 (Chapter 5) showed that drivers' THW was significantly higher when there was no other vehicles present in traffic and with an increasing traffic density, participants were keeping a THW that was increasingly closer to the minimum they would prefer to adopt. In study 3 (Chapter 6), participants exhibited a whole range of changes including to their following tactics, workload and safety behaviour, seemingly influenced by the THW kept by vehicle involved in platoon in the adjacent lane. Finally, study 4 (Chapter 7) showed an increase in some dimensions of subjective workload measured as a result of an increased traffic density (perceived workload).

One difficulty in investigating the behavioural adaptation of UVDs is that drivers have to be aware at some level of the changes induced by the presence of automated systems in traffic to be influenced by them. The probability of noticing changes induced by systems implemented in other vehicles is lower than when the drivers are directly interacting with the system in their own car. This is because when drivers are directly interacting with systems in their cars, it generally has an immediate impact on their primary driving task. The SEEV Model by Wickens et al. (2001) presented Chapter 2 explains that the probability of attending to a visual channel depends on four factors that either attract (Salience, Expectancy, Value) or repulse attention (Effort). Thus, the visual channel

where the automated systems are present should not be in competition with other visual channels attracting attention with information that is more valuable in accomplishing the driving task. The fourth experimental study (Chapter 7) stressed the importance of the factors exposed in the SEEV model. The lack of significant results can be interpreted as the predominance of effort or mental workload generated by the primary driving task, inhibiting the direction of attention toward the visual channel where the platoons were present.

In summary, the complexity of the phenomenon of behavioural adaptation, especially concerning those of UVDs, directs the academic community to focus on that research area. The focus is important as behavioural adaptation of UVDs could have implications for overall traffic safety. Moreover, such research will be significant, as the fleet trends towards a mix of UVDs and equipped vehicle drivers (EVDs). Throughout the lifetime of this PhD, considerable milestones have been successfully achieved in other activities making automated driving a realistic future scenario: the 2012 Vislab Intercontinental project, the SARTRE project successfully accomplished in 2012 and OEMs (Google, BMW, Audi, Continental and Bosch) that launched test from 2010 with ‘self-driving’ cars on real roads in states of the USA (“Look, no hands”, 2012). ADAS combining both lateral and longitudinal control of the vehicle that are on the brink of market introduction, such as the Autopilot system announced by Volkswagen (Bartels et al., 2011), illustrate the rapid progression toward more fully-automated driving, which will probably include short-headway platoons in the future.

The recent development of ‘self-driving’ cars, together with the development of CACC, also has the aim of reducing the space between vehicles. Critically, such technology is likely to be implemented on normal roads – without special lanes for equipped vehicles. Different forms of automation are emerging and it appears that regardless of which form is going to become popular on our roads, there is a consensus developing that it will be accompanied by a reduction in THW. The form of automation currently in development were all announced with a planned reduction in vehicles’ THW: platoon (Dávila & Nombela, 2010, October; Lank et al., 2011), CACC (Van Arem et al., 2006), AHS (Horowitz & Varaiya, 2002) and ‘self-driving’ cars (“Look, no hands,” 2012). This

reinforces the need to investigate the impact on UVDs and it shows that the results found in this work may also be more applicable to other automated driving systems, not only platooning.

However, this work emphasises the paucity of knowledge in this area and considerable work will need to be done to fully understand the behavioural adaptation of UVDs exposed to mixed traffic. The implication for the research community is that there is a pressing need to conduct more research investigating the phenomenon. There are also implications for policy makers and road management authorities to develop good practice in systematically investigating the impact of ADAS and automated driving on UVDs in order to prevent any undesirable effects.

8.3 Limitations

The interpretation and generalisation of the results presented in this thesis should be undertaken with some caution as a number of limitations have to be considered. The limitations occurring within each of the objective areas are discussed in the following sub-sections.

Objective 1: Development of a method

- The first limitations requiring attention concerns the use of a simulator to conduct the experimental studies. Briefly, as described in Chapter 3, driving simulators were chosen as a tool to investigate behavioural adaptation for ethical reasons (potential risky traffic scenarios) as well as technical constraints (e.g. availability of the required equipment) and experimental constraints (control of the environment). However, the use of a driving simulator raises many concerns. Firstly, whether results from the driving simulator studies can be extended to allow predictions regarding real-world behavioural adaptation of UVDs. It is particularly questionable as to whether a driving simulator is an appropriate tool to investigate any social aspect of the driving task. This concern was mentioned in Chapter 3. In order to expect an impact of the social environment, participants probably need to have the impression that real people are driving the cars in the simulated world. In contrast, if participants do not perceive that real people are driving the cars, they might attribute any unfamiliar behaviour (such as short THW) to the fact that behaviour is being generated by a computer. Therefore it is unclear whether the effects found in the simulator studies are applicable to the reality. Arguably, this

may limit the extent to which behavioural adaptation may occur in a simulated environment and that the effect of short THWs in platoons could actually be larger in the real world. This limitation ought to be considered in further studies. One approach to tackle this problem would be to study the simulator's validity for measuring the influence of other drivers in traffic. Alternatively, the drivers' feeling of presence in the simulated scenario could be assessed in parallel (i.e. the extent to which drivers believe they are actually driving on a real road with real traffic, rather than sitting in a laboratory). Moreover, it may be worth considering in the future using networked simulators in which multiple 'real' drivers interact in a single virtual driving world.

Another problem linked with the issue of the feeling of reality in the simulated environment is the feeling of risk. As participants are conscious that they are performing in a simulated world, they might feel more inclined to take risks in a driving simulator than in the real environment. For instance, participants could have been inclined to drive closer to the LV on the assumption that, for example, unexpected braking reaction of the LV was unlikely and even if it did occur, the consequences for them as a driver and any other road users are much less than in the real environment. Finally, although a key benefit of simulators is that they enable investigations to be conducted in a carefully controlled framework, this makes results difficult to generalise to the real-world given the enormous variability inherent in typical real world road traffic scenarios (i.e. limited ecological validity).

Objective 2: Parameters favourable to the emergence of behavioural adaptation

- Objective 2 did not lead to an investigation in a dedicated experimental study where environmental factors were systematically varied in the design. Including environmental factors would have dramatically increased the number of factors to consider, thus impacting on the total length of the experimental trials. It was considered to be important to avoid long duration drives, as they may have impacted car-following behaviour in a way that is contrary to the effect being investigated (Fuller, 1984). Consequently, it was decided to postpone investigations of environmental factors to later stages and to concentrate first on gathering evidence for behavioural adaptation of the UVDs. The method underwent modifications throughout the

work in an attempt to understand the conditions most likely to provoke significant changes in drivers' behaviour. The variation of elements in the scenario carried out in this work sets the stage for comparative studies permitting the generation of hypotheses relating to environmental factors which could be tested in later experimental studies.

Objective 3: Influence from inter-individual characteristics

- One limitation in the fulfilment of the objective 3 is that no assessment of inter-individual characteristics was made in study 1 and 3. As significant behavioural adaptation effects were found in study 3, it is proposed that good future opportunities exist to investigate which traits are favourable for behavioural adaptation. It would be of value to include such measures in any studies that apply a similar methodology to that applied in this thesis.

Objective 4: Conformity to the new norm established by platoons keeping short THWs

- In order to address objective 4, a method of limits was used to assess participants' minimum preferred THW. This was compared with the THW adopted by drivers during simulated drives. The results showed that individual drivers selected a preferred THW that was consistent over time and condition. As expected, the minimum adopted THW varied significantly across the different drives supporting the idea that adopted THW depends on situational factors. In none of the conditions did drivers adopt a THW below their preferred THW, but in platoon conditions and especially in THW03 drivers adopted THWs very close to the limit of preferred THW. It can be concluded that in this experimental study, platoons with short THWs lead drivers to drive closer to their limits. However, it is not clear what would have been the consequences (e.g. in terms of safety, workload, performance) of drivers keeping THWs below the minimum preferred THW. Further experimental studies are needed to investigate this issue.

8.4 Further research and outlook

The present work succeeded in showing that an effect of EVDs on UVDs exists, but results also showed that many factors impact on the behavioural adaptation of UVDs. Thus, this work did not

only show that this new research path is worthwhile, it also showed that much research is still required to understand the conditions for behavioural adaptation and the mechanisms accounting for behavioural adaptation on UVDs leading to a better understanding of the implications for driver safety. Beyond that, work can be conducted to develop countermeasures to such behavioural adaptation and safeguard drivers' safety. This section outlines the gap in knowledge remaining on the mechanisms, the further variables to investigate and explore possible countermeasures to mitigate negative effects of automated platoon driving on UVDs.

8.4.1 Mechanisms underlying behavioural adaptation

The theoretical background supporting the hypothesis of a behavioural adaptation of UVDs to short THWs in platoons entangles perceptual and social mechanisms. This work focused primarily on the research of evidence for behavioural adaptation of the UVDs. Now that some evidence was found, especially in study 3, more focus needs to be directed on the mechanisms underlying behavioural adaptation of UVDs to short THWs in platoons. Additional work is required to understand whether the mechanisms are jointly responsible for behavioural adaptation of the UVDs or if one is more predominant. This can be addressed using the variable "vehicle type". Cars were selected to form the platoons in study 2 as it was assumed that drivers are keener to reproduce behaviour from other drivers that are similar to themselves. Trucks were used in the platoon in study 3 instead of cars to increase saliency in the visual channel with platoons, increasing the probability of non-platoon drivers' to allocate their attention to the channel and hence to be influenced by platoons. It appears that the type of vehicles forming a platoon can inform on the underlying processes of behavioural adaptation of UVDs: a behavioural adaptation occurring when platoons are formed with cars would support the influence of social mechanisms whereas a behavioural adaptation occurring with trucks in platoons would support the influence of perceptual mechanisms.

Further experimental studies with vehicle type introduced as an independent variable in the design study would enable to better understand the underlying mechanisms of behavioural adaptation.

8.4.2 Further variables

This work illustrated the impact of short THWs on UVDs in very specific driving scenarios. However, behavioural adaptation arises as a result of a complex interaction between the elements of the driver-vehicle-environment system. Therefore, small changes in one or more elements of the scenario may impact the magnitude or direction of behavioural adaptation. It is a limitation of this work that the impact of only few variables was tested and their variation was not necessarily tested in a single experimental trial (see the limitation of objective 2 in section 9.3).

Considering the driver-vehicle-environment system, it can be argued that three main elements will determine the occurrence of behavioural adaptation: the constitution of traffic as part of the environment, the characteristics of the vehicles in traffic equipped with ADAS or automated systems, and finally the characteristics of the UVDs themselves.

Characteristics of the traffic:

- Variations could be investigated of typical traffic characteristics such as the penetration rate of automated driving but also the traffic flow and the traffic density.
- The scenario presented in the experimental studies suffered a lack of realism as they were rather simplified. Further studies could be set in more typical driving situations.

Characteristics of the equipped vehicles:

- Platoon characteristics may influence drivers' behavioural adaptation. For instance, the implications of the THW between vehicles in a platoon are unclear. It is also uncertain whether the contagion effect has a linear association with THW or if there is a plateau effect.
- It is conceivable that the type of vehicles constituting the platoon influences the effect on UVDs. On the one hand, trucks are certainly more conspicuous due to their size, increasing the probability that unequipped car drivers will direct their attention toward them. On the other hand, drivers of unequipped cars are perhaps more likely to adopt the same behaviour as that observed of vehicles similar to their own.

- Other characteristics of equipped vehicles might also have an impact on UVDs such as the length of platoon formed by automated vehicles, the platoon speed or any other changes in vehicles' dynamic (e.g. acceleration). Also, any feedback to other drivers might have an impact.

Characteristics of unequipped vehicles' drivers:

- The impact of UVDs' characteristics was only touched upon in this work. Some attributes such as personality traits or demographic characteristics might be more likely to induce behavioural adaptation than others and again, this might depend on the prevailing situational factors (Chapter 5, section 5.5).
- Also, drivers' skills in the car-following task were found to be a promising factor to distinguish drivers. In Chapter 6, the idea was raised of a possible duality of drivers' longitudinal control with an open-loop control and a closed-loop. Although the proposed separation between the two control processes needs validation, it could be helpful for understanding drivers' following behaviour and how it is impacted by environmental factors such as the presence of UVDs in traffic.
- Furthermore, it seems that mental states such as emotions and workload can influence whether behavioural adaptation of UVDs occurs. The effect found in the experimental study 3 (Chapter 6) was interpreted as a result of the high motivation of participants to track the LV, whereas the lack of effects in the experimental study 4 (Chapter 7) was considered to arise due to the relatively high workload of drivers as a result of frustration induced by the primary driving task.
- Finally, cognitive processes can have a substantial impact on behavioural adaptation too. As part of cognitive processes, attention is relevant in the research on behavioural adaptation of the UVDs, as it has to be ensured that these drivers will attend the visual channel where EVDs are present. The SEEV model from Wickens et al. (2001) gives an overview of the factors responsible in the probability of attending to a specific channel. Moreover, as another part of cognitive processes, the impact of mental models on the system has not been investigated here. It was maintained constant throughout the different experimental studies that participants did not receive any information about the system properties. Mental models can be formed either

through indirect feedback (via the media) or through direct feedback provided to drivers such as signs on the roadside, or simply through system properties inducing obvious changes. Further work is required to investigate how different types of mental model will impact on UVDs. It is also a question, whether the constitution of an appropriate mental model will mitigate any behavioural adaptation of the UVDs. Will UVDs, aware of the danger of a contagion effect, avoid a reduction in their own THW?

8.4.3 *Countermeasures*

If behavioural adaptation is observable in a consistent way and in a way that is a threat for drivers' safety or that limits the effectiveness of platooning, then countermeasures should be investigated. Behavioural adaptation may be influenced using a range of traditional methods, typified by the "three E's": Education, Enforcement and Engineering. Some ideas in this direction are described here. Before applying the countermeasures, it is important though to understand the mechanisms underlying behavioural adaptation. The effectiveness of countermeasures will depend on whether they target the right mechanisms. Despite the gap of knowledge remaining on the mechanisms responsible for behavioural adaptation, some countermeasures will be suggested that should be considered with caution. Different measures may be engineered to avoid any untoward effect of behavioural adaptation. Some may be implemented on platoons themselves. To avoid any social mechanisms to operate, one idea would be to make platoons look like a separate entity. Rules enumerated by the Gestalt psychology (Metzger, 1954) could be applied to make platoons look like a separate entity. Rules that could be applied in this context are for instance the law of proximity or law of similarity. The law of proximity is put into practice anyway when cars are driving sufficiently close together and the law of similarity could be put into practice in, for instance, using a certain light pattern for vehicles belonging to the same platoon. Still, it is questionable whether according to these laws, platoons are perceived as a distinct entity and whether the perception of platoons as a separate entity would mitigate any negative impact on UVDs.

In case, behavioural adaptation is the result of perceptual mechanisms all vehicles could be fitted with a system warning against unsafe THW. A study conducted by Fairclough, May, and Carter

(1997) has shown that the presence of such a system reduced the proportion of time participants spent at a short headway.

Educational measures such as chevrons painted on the road surface could also be used against negative effects due to platoons. In addition, informing the driver about the risk either through special training or warning signs at the entrance of a zone dedicated to platoons could be effective.

Finally, enforcement could support the other measures. Increasing the control of THW kept by vehicles and using legal sanction to prevent close-following could urge drivers to be more vigilant toward their own THW. Enforcement could also constrain the use of platoons, perhaps so they are only permitted within certain areas or at specific times of the day.

9 CONCLUSIONS

The present work investigated potential contagion effects of short THWs maintained in platoons on the UVDs nearby. It was hypothesised that the increasing penetration of EVDs in the traffic able to keep short THW for all the benefits it causes, would change the norm upon which THW is safe to keep. Arguably, UVDs could then try to keep a shorter THW to match the new norm established on the road.

Based on four studies conducted in this PhD work, it is concluded that behavioural adaptation to the short THW within platoons can occur in certain driving conditions. The work has highlighted the absence of research on the behavioural adaptation of UVDs to the presence of automated systems in traffic and that a large range of distinct variables might impact on the magnitude and direction of behavioural adaptation. However, it is still unclear what the effect of many of these variables on the UVDs will be. Further studies are therefore required to investigate the impact of these variables on UVDs' behavioural adaptation and to examine in which conditions the interaction may be unsafe. Thus, this work has opened several new opportunities for research. Beyond the focus presented here and because other systems' characteristics might affect UVDs, it is of paramount importance to develop good practice in systematically investigating the impact of ADAS and automated driving on the UVDs in order to prevent any undesirable effects.

If vehicles become autonomous and do not rely solely on human action, the car may become less of a means of expression of social status. Social interaction might then be directed from the external world toward the interior of the vehicle. This raises concerns upon the interaction with other road users, not equipped with such system, such as UVDs, motorcyclists and pedestrians. Will these unequipped road users be able to understand systems enabling automated driving – how to behave in their presence and interact with them? What will the perception of other road users be and will they be able to understand the new behaviours? How will they change their behaviour in reaction toward these systems? Are they going to be influenced by these systems? Are automated systems going to change the norms prevailing on the roads? The work presented in this thesis suggests that there may be subtle and complex changes when autonomous systems are introduced to the vehicle fleet, understanding of which may improve acceptance and ultimately the safety of road transport.

10 LITERATURE

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APPENDIX A: Participants' written consent form used in all studies

WRITTEN CONSENT FORM



PLEASE **WRITE YES** OR **NO** IN THE SPACE PROVIDED

YES or NO

Have you read the Participant Information Letter?

Have you had an opportunity to ask questions about the study?

Have you received satisfactory answers to all your questions?

Have you received enough information about the study?

Do you understand that you are free to withdraw from the study...

...at any time?

...without having to give reason for withdrawing?

You should only agree to take part in this study when all your answers to the above questions are yes

Do you agree to take part in this study

Participant Name: _____ Signature: _____

Date: _____

Trials Manager: _____ Signature: _____

Date: _____

Please complete and sign both consent forms. This one is for you to keep and the other for TRL.

APPENDIX B: Participants' instruction used in the 1st experimental study

Participant information

Thank you for participating in this research. The following text gives you the instruction for the study.

For this study you will drive three routes. Each drive lasts about 10 minutes. In total, the trial should not be longer than 40 minutes.

Your task is to follow a lead vehicle. Imagine that you are invited for a birthday party and you don't know the route. A friend of you is invited for the same party and knows the route. He is driving in front of your car so that you can follow him. Thus, don't lose track of him!

Please remember that it is important that you drive as you would normally.

You will also be asked to complete questionnaire before and after each drive.

Before starting the vehicle, please adjust your seat and the mirror and fast your seat belt. To start the vehicle, turn the ignition key then drive as you will normally do! The vehicle has a manual transmission.

Thanks again

APPENDIX C: Participants' questionnaire used in the 1st and 3rd experimental studies

To be completed by TRL	
Participant Number: _____	Date: ____/____/____ Drive order: _____
Driving Simulator Study	

SECTION A. Background information (to be administered before trials)			
<p>Note:</p> <ul style="list-style-type: none"> All information on this form is confidential. It will be stored securely at TRL. No information will be used by other projects at TRL. No individuals will be identified. 			
Aa) Name:			
Ab) Please state your age in years:			
A,			
Ac) Please state your sex (tick):			
<i>Male</i>		<i>Female</i>	
Ad) Please state your occupation:			
Ae) Please state the year when you obtained your full driving licence:			
Af) Please state your estimated annual mileage:			

APPENDIX D: Participants' debriefing sheet used in all studies

Participant debriefing

Thank you very much for your participation in this study.

Since you successfully completed the simulator trial, we now can reveal the real purpose of the study.

The aim of this study is to investigate whether people reduce their safety distance when driving in the presence of convoys or platoons of vehicles that maintain a very small safety distance.

A platoon consists of several vehicles, whereupon the first driver operates manually, while the other vehicles follow fully automatic (lateral and longitudinal guidance). It is designed to be used on the highway system when vehicle drivers occasionally meet and head in the same direction for a long period of time.

As consequence of the simulator trial, it is possible that you unconsciously reduced the safety distance that you would normally adopt. Although small, there is a possibility that you may also adopt a smaller safety distance when driving in the real world on your way back home. Maintaining a small safety distance with the car in front of you has of course important safety implications and we therefore ask you to be extra careful and aware of your following distance when leaving TRL by car. **It is very important, that you bear in mind that the recommended time headway in the UK is 2 seconds!! It is very important that you keep this safety distance for your next drives!!**

Again, thank you very much for having participating in this research and if you have questions, please feel free to ask the researcher.

Thanks again

APPENDIX E: Participants' instruction used in the 2nd experimental study (without part 2 and 3 in the 3rd experimental study)

Participant information

Please read carefully the below text in which it is explained what you are asked to do in this study. If you have any questions, please do not hesitate to ask the experimenter.

For this study you will be asked to perform three different driving tasks:

1. Active drives

In an active drive you are asked to follow a red vehicle that is driving in front of you (see Fig.1).



Figure 1

Imagine that you are invited for a birthday party and you don't know the route. A friend of you is invited for the same party and knows the route. He is driving in front of your car so that you can follow him. So, don't lose track of the car.

In order to get accurate data, you are asked to stay in the same lane throughout the drive, and not to leave too large a gap to your friend's car. A message will appear on the screen if you are either too far behind or if you are drifting in the adjacent lane (see Fig. 2).

However, please remember that it is important that you drive as you would normally in such a situation.



Figure 2

2. Passive drives

In a passive drive your car will drive automatically. This means that you don't have to steer or use the pedals but please keep your hands on the steering wheel as if you were driving.

You will be watching a set of increasing and a set of decreasing distances.

After each presentation, the screen will be blanked and you are asked to respond **'yes'** if you would normally keep the distance previously displayed or **'too short'** or **'too large'** (see Fig. 3).

Similarly to the active drives, imagine that you are following a friend who knows the route to a birthday party.

Next page →

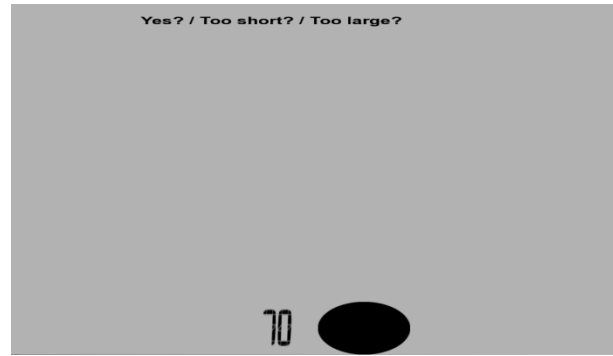


Figure 3

3. Familiarisation

Before starting with the actual study, you will be asked to have a drive in the simulator just to familiarise yourself with the controls and handling of the simulator vehicle as it is different from driving a real vehicle. During this drive, you are asked to follow a lead vehicle whilst keeping a safe and constant distance between you and the vehicle. After 10 minutes, you will be asked whether to continue or stop the drive. If you feel familiarise with the vehicle, then stop. If not then continue the drive until you think you are familiarised.

In total, you will be asked to do a ~10 minutes familiarisation drive, 3 active drives of 7 minutes and 4 passive drives of ~5 minutes (see Fig.4).

Familiarisation	Passive drive 1	Active drive 1	Passive drive 2	Active drive 2	Passive drive 3	Active drive 3	Passive drive 4
10 min	~5 min	7 min	~5 min	7 min	~5 min	7 min	~5 min

Figure 4

Between each drive, you will also be asked to fill out a brief questionnaire and you will have the opportunity to have a break. Before starting the vehicle, please adjust your seat. To start the vehicle, hit the button for the ignition on the gearbox key then drive as you normally do! The vehicle has a manual transmission and 5 gears.

Please keep in mind:

- Try to drive as you would normally.
- This is not a game.
- You can't do anything wrong.

Thanks again for your participation!

APPENDIX F: Participants' questionnaire used in the 2nd and 4th experimental studies

To be completed by TRL

Participant Number: _____

Date: ____/____/____

Drive order: _____

Driving Simulator Study

SECTION B. Background information (to be administered before trials)

Note:

- All information is confidential.
- It will be stored securely at TRL.
- No information will be used by other projects at TRL.
- No individuals will be identified.

Ag) Name:

--

Ah) Please state your age in years:

A,

Ai) Please state your sex (tick):

<i>Male</i>		<i>Female</i>	
-------------	--	---------------	--

Aj) Please state your occupation:

--

Ak) Please state the year when you obtained your full driving licence:

--

Al) Please state your estimated annual mileage:

--

After Familiarisation

No one is perfect. Even the best drivers make mistakes, do foolish things, or bend the rules at some time or another. Some of these behaviours are trivial, but some are potentially dangerous. For each item below you are asked to indicate HOW OFTEN, if at all, this kind of thing has happened to you. Base your judgements on what you remember of your driving over, say, the last year. Please indicate your judgements by checking ONE of the columns in the grid next to each item. These columns are headed by numbers between 0 and 5. These mean the following:

- 0 = Never
- 1 = Hardly Ever
- 2 = Occasionally
- 3 = Quite Often
- 4 = Frequently
- 5 = Nearly all the time

	Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
	0	1	2	3	4	5
Attempt to overtake someone that you hadn't noticed to be signalling a right turn						
Stay in a lane that you know will be closed ahead until the last minute before forcing your way into another lane						
Miss 'Stop' or 'Give Way' signs and narrowly avoid colliding with traffic having right of way						
Pull out of a junction so far that the driver with right of way has to stop and let you out						
Fail to notice that pedestrians are crossing when turning into a side street from a main road						
Drive especially close to the car in front as a signal to its driver to go faster or get out of the way						
Sound your horn to indicate your annoyance to another driver						
Queuing to turn left onto a main road, you pay such close attention to the mainstream of traffic that you nearly hit the car in front						
Cross a junction knowing that the traffic lights have already turned against you						
On turning left nearly hit a cyclist who has come up on your inside						
Disregard the speed limit on a motorway						
Fail to check your rear-view mirror before pulling out, changing lanes, etc.						
Become angered by a certain type of driver and indicate your hostility by whatever mean you can						
Become impatient with a slow driver in an outer lane and overtake on the inside						
Underestimate the speed of an oncoming vehicle when overtaking						
Race away from the traffic lights with the intention of beating the driver next to you						
Brake too quickly on a slippery road, or steer the wrong way in a skid						
Drive even though you suspect you may be over the legal blood-alcohol limit						
Disregard the speed limit on a residential road						
Become angered by another driver and give chase with the intention of giving him/her a piece of your mind						

After passive drive 1

You will find in the following some opinions stated by various drivers concerning causes of accidents. Please express your degree of agreement or disagreement with each statement, selecting a number from the following scale:

0 = Disagree very much

1 = Disagree quite a bit

2 = Disagree some

3 = agree a little

4 = agree quite a bit

5 = agree very much

	Disagree very much	Disagree quite a bit	Disagree some	agree a little	agree quite a bit	agree very much
	0	1	2	3	4	5
1) Driving with no accidents is mainly a matter of luck						
2) Accidents happen mainly because of different unpredictable events						
3) The driver can do nothing more than drive according to traffic regulations						
4) Accidents happen because of so many reasons we will never know the most important one						
5) People who drive a lot with no accidents are merely lucky; it is not because they are more careful						
6) The careful driver can prevent any accident						
7) When a driver is involved in an accident, it is because he did not drive as he should						
8) When a driver is involved in an accident it is because he did not pay attention to his driving						
9) Accidents are only the result of mistakes made by the driver						
10) The driver is to be blamed almost always when an accident occurs						
11) It is difficult to prevent accidents in bad conditions such as darkness, rain, narrow roads, curves, and so on						
12) Most accidents happen because of bad roads, lack of appropriate signs, and so on						
13) It is very hard to prevent accidents involving pedestrians who come out from between parked cars						
14) Accidents in which children are involved are hard to prevent because they do not know how to be careful						
15) It is very hard to prevent accidents in which old people are involved because they cannot hear nor see well						
16) Accidents happen because drivers have not learned how to drive carefully enough						
17) It is always possible to predict what is going to happen on the road and so it is possible to prevent almost any accident						

	<i>Disagree very much</i>	<i>Disagree quite a bit</i>	<i>Disagree some</i>	<i>agree a little</i>	<i>agree quite a bit</i>	<i>agree very much</i>
	0	1	2	3	4	5
18) Accidents happen when the first driver does not take into consideration all the possible actions of the second driver						
19) Accidents happen because the driver does not make enough effort to detect all sources of danger while driving						
20) Most accidents happen because of lack of knowledge or laziness on the part of the driver						
21) If you are to be involved in an accident, it is going to happen anyhow, no matter what you do						
22) Most accidents happen because the second driver does not pay attention to traffic regulations even when the first driver does						
23) The driver does not have enough control over what happens on the road						
24) Most accidents happen because of mechanical failures						
25) There will always be accidents no matter how much drivers try to prevent them						
26) Accidents happen when the driver does not take into consideration all the possible behaviours of pedestrians						
27) Accident-free driving is a result of the driver's ability to pay attention to what is happening on the roads and sidewalks						
28) The driver can always predict what is going happen; that is why there is no room for surprises on the road						
29) It is possible to prevent accidents even in the most difficult conditions such as narrow roads, darkness, rain, and so on						
30) Prevention of accidents depends only on the driver and his characteristics rather than on external factors						

For the following questions please think about the drive you just completed.

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

For the following questions please think about the drive you just completed. Please evaluate your driving behaviour during this drive on the following scales:

Distance to the lead vehicle:

very close --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- very far

Speed:

very low --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- very high

After passive drive 2

Please use the rating scale to the right to describe how accurately each of the below statements describe *you*.

Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age.

	Very little	Little	Moderate	Much	Very Much
D1. Love excitement.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D2. Get angry easily	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D3. Worry about things	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D4. Make people feel welcome	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D5. Seek adventure.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D6. Get irritated easily	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D22. Fear for the worst	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D32. Anticipate the needs of others	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D3. Love action	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D13. Get upset easily	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D23. Am afraid of many thing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D33. Love to help others	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D4. Enjoy being part of a loud crowd	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D14. Am often in a bad mood	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D24. Get stressed out easily	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D34. Am concerned about others	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D5. Enjoy being reckless	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

		Very little	Little	Moderate	Much	Very Much
D15.	Lose my temper	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D25.	Get caught up in my problems	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D35.	Have a good word for everyone	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D6.	Act wild and crazy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D16.	Rarely get irritated	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D26.	Am not easily bothered by things	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D36.	Look down on others	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D7.	Willing to try anything once	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D17.	Seldom get mad	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D27.	Am relaxed most of the time	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D37.	Am indifferent to the feelings of others	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D8.	Seek danger	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D18.	Am not easily annoyed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D28.	Am not easily disturbed by events	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D38.	Make people feel uncomfortable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D9.	Would never go hang gliding or bungee jumping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D19.	Keep my cool	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D29.	Don't worry about things that have already happened	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D39.	Turn my back on others	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D10.	Dislike loud music	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D20.	Rarely complain	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D30.	Adapt easily to new situations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D40.	Take no time on others	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

After passive drive 3

Please circle the number that represents how you feel about each statement

It is all right to do anything you want as long as you keep out of trouble

Strongly disagree --- 1 --- 2 --- 3 --- 4 --- 5 --- strongly agree

It is OK to get round laws and rules as long as you don't break them directly

Strongly disagree --- 1 --- 2 --- 3 --- 4 --- 5 --- strongly agree

If something works, it is less important whether it is right or wrong

Strongly disagree --- 1 --- 2 --- 3 --- 4 --- 5 --- strongly agree

Some things can be wrong to do even though it is legal to do it

Strongly disagree --- 1 --- 2 --- 3 --- 4 --- 5 --- strongly agree

After passive drive 4

Did you notice any differences between the three long drives?

1st drive:

2nd drive:

3rd drive:

Passive drive (for the experimenter)

1st assessment

(export channel = 0 or 20, value = 2)

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

(export channel = 0 or 20, value = 1)

2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Comments: -----

2nd assessment

(export channel = 0 or 20, value = 1)

2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

(export channel = 0 or 20, value = 2)

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Comments: -----

3rd assessment

(export channel = 0 or 20, value = 2)

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

(export channel = 0 or 20, value = 1)

2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Comments: -----

4th assessment

(export channel = 0 or 20, value = 1)

2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

(export channel = 0 or 20, value = 2)

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Comments: -----

APPENDIX G: Participants' instruction used in the 4th experimental study

Participant information

Welcome to this study of driver's perception in time pressure!

Please read carefully the below text in which it is explained what you are asked to do in this study. If you have any questions, please do not hesitate to ask the experimenter.

For this study you will be asked to perform two different driving tasks on a three lane motorway.

4. Active drives

Imagine that you are late for a meeting. Regularly the right lane will be closed because of engineering work but the speed limit remains 70 mph.

5. Passive drive

In a passive drive your car will drive automatically at 70 mph. This means that you don't have to steer or use the pedals but please keep your hands on the steering wheel as if you were driving.

You will be watching a set of increasing and a set of decreasing distances. After each presentation, the screen will be blanked and you are asked to respond loudly 'about right' if you would normally keep the distance previously displayed or 'too close'.

In total, you will be first asked to do 1 passive drives of ~5 minutes and then 3 active drives of ~15 minutes (see Fig.1).

Passive drive 1	Active drive 1	Active drive 2	Active drive 3
≈5 min	15 min	15 min	15 min

Figure 1

Between each drive, you will also be asked to fill out a brief questionnaire and you will have the opportunity to have a break. Before starting the vehicle, please adjust your seat. The vehicle has a manual transmission and 5 gears.

Before starting with the actual study, you will be asked to have a drive in the simulator just to familiarise yourself with the controls and handling of the simulator vehicle as it is different from driving a real vehicle. During this drive, you are asked to follow a lead vehicle whilst keeping a safe and constant distance between you and the vehicle. Stop when you feel familiarised.

Please keep in mind:

- Try to drive as you would normally.
- This is not a game.
- You can't do anything wrong.

Thanks again for your participation!

APPENDIX H: Key criteria of the psychophysical method of limits

Introduction

The study presented in chapter 5 introduced the psychophysical method of limits in the realm of car-following studies to assess the threshold of drivers' preferred THW.

The method controls the influence of situational factors as the choice of a preferred THW is the result of a perceptual decision only and there is no need for the driver to regulate THW according to a certain situation. The preferred THW was then compared with the adopted THW when driving in different traffic conditions: a car-following drive next to a platoon of vehicles (i.e. an uninterrupted line of identically closely spaced vehicles) maintaining a THW of either 0.3 sec or 1.0 sec and a control condition with no platoon. Assessment of preferred THW took place after each of the three drives. The idea behind the use of the method of limits was to compare adopted and preferred THW, which would show whether drivers went below their perceived limits as a result of platoons' influence. However, as the method of limits has never been used before to measure preferred THW, it would be prudent to verify first the validity and reliability of the obtained parameter. Therefore, the present chapter is using results obtained in the second experimental study to analyse the reliability and validity of the method of limits for the measure of preferred THW.

Results

Reliability

One of the key criteria in the test theory is reliability. Reliability refers to the consistency of a measure. Specifically, a test is considered as reliable if results obtained from repeated measure are consistent. This section is therefore analysing the test-retest variability of the method as the measure has been repeated three times in the course of the study.

The assumption of normality was violated for one level of the factor minimum preferred THW (THW10) and one level of the factor minimum adopted THW (Baseline). However, a decision was made to retain the use of ANOVA statistics as there is substantial evidence for its robustness with

regards to the empirical α and β values, whilst use of non-parametric is associated with a loss of precision that comes along with transformation into rank data (Schmider et al., 2010).

The averaged preferred minimum THW measured in conditions BL ($M = 1.36$; $SD = .59$), THW03 ($M = 1.30$; $SD = .58$) and THW10 ($M = 1.28$; $SD = .53$) did vary significantly, $F(2, 82) = 3.26$, $p = 0.04$, $\eta_p^2 = .14$. The Cronbach's alpha test (Van Winsum & Heino, 1996) was applied to evaluate the consistency of the three measurements of preferred minimum THW and showed internal consistency ($\alpha = .83$). The good correlation (Kline, 2000) between the preferred THWs is further evidence for internal consistency of the psychophysical method of limits applied to the measure of minimum preferred THW.

Variability

The other key criterion of test theory is the validity, which represents the degree to which the tool measures what it claims to measure. The validity is measure in comparing the obtained parameter to the one obtained in a more realistic drive, which are the simulator drives.

Correlation between minimum adopted THW and minimum preferred THW was computed with the non-parametric rank correlation coefficient Spearman's rho as the Pearson's assumption of normality was violated (Figure 50). There was a significant and high correlation according to Cohen's definition (1992) between minimum adopted and minimum preferred THW in BL ($\rho = .83$, $p < .05$), THW03 ($\rho = .63$, $p < .05$) and THW10 ($\rho = .82$, $p < .05$). There is strong evidence of a relationship between the different minimum adopted and minimum preferred THW, and that the psychophysical method of limit measuring minimum headway therefore has predictive validity.

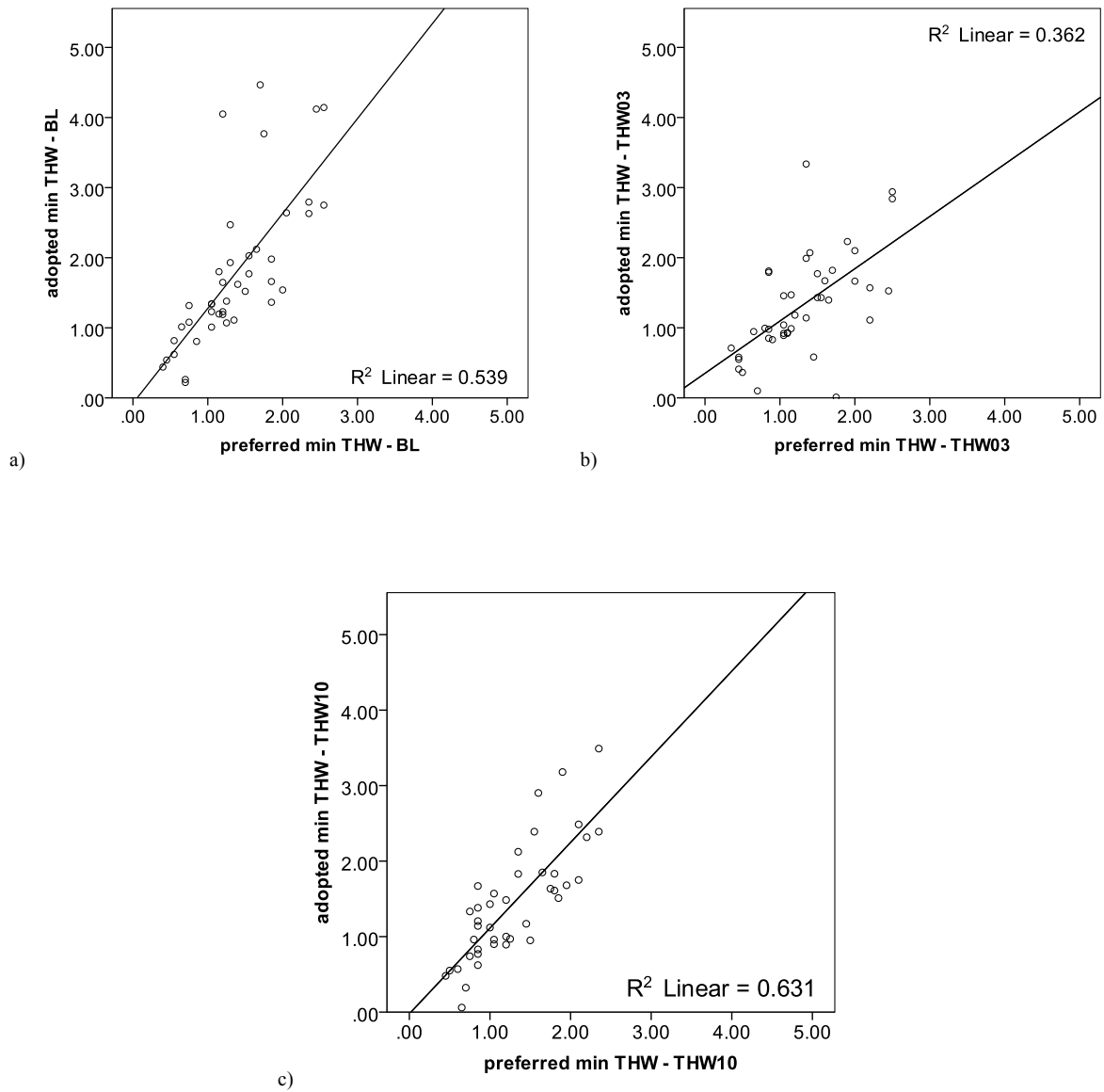


Figure 50 Scatter plot with line of best fit for minimum adopted and preferred THW in condition BL (a), THW03 (b), THW10 (c) (N = 42)

After each drive, participants were asked to rate their distance on a 7-point scale (1= very close, 7= very far). The averaged values were close to the neutral answer (= 4) (Figure 51) in each drive and there is no significant difference between the three conditions [$\chi^2(2) = 2.48$, $p = 0.29$]. These results present evidence that drivers always considered themselves within the margin of their preferred THW.

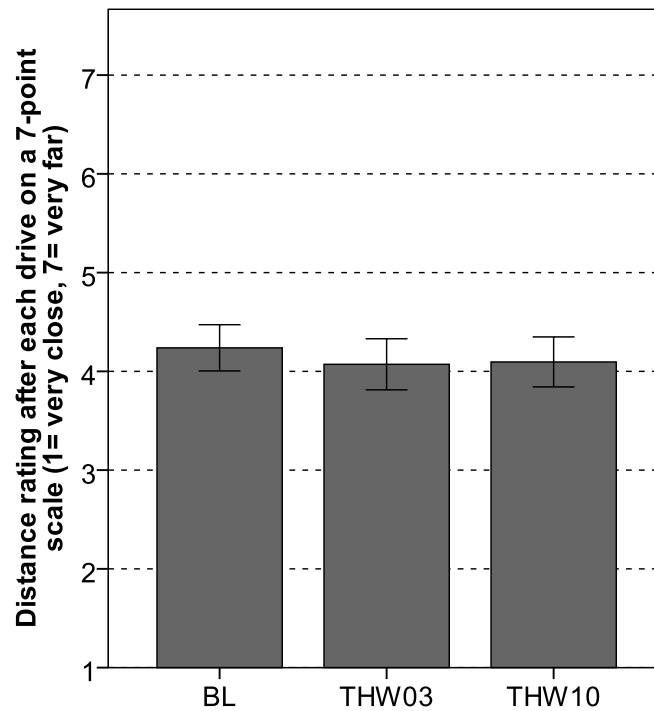


Figure 51 Mean rating on a scale completed after each simulator drive for the measure of adopted THW (N = 42): participants had to rate the distance kept in the previous drive on a scale from 1 (=very close) to 7 (= very far).

Conclusions

The aim of the present chapter was to analyse results obtained in the second experimental study to explore the key criterion of the psychophysical method of limits when implemented in the realm of car-following to measure the lower threshold of preferred THW. The results showed that individual drivers selected a preferred THW that was consistent over time and condition and there is a consistency between minimum preferred and adopted THW.

Therefore, the method developed appears to be a reliable, valid and efficient technique for capturing minimum preferred THW in controlling situational factors, without requiring the use of an instrumented vehicle. In addition to its use in driver behavioural research, this method could be useful as a prediction tool for driver training to detect unsafe driver behaviour and to coach improvements in driving style.